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Foredune Response to Storm Erosion and the Role of Vegetation in Recovery

Christopher J. Virtue

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Abstract

Erosional scarping of beaches as a result of the June 6th 2016 storm event provided an opportunity for coastal managers to increase knowledge regarding the impacts of large storm events on beach-dune systems. The recovery of scarps through slumping has not been widely investigated, with previous studies focused on beach response to storm events as an overview. The Illawarra and south coast region was examined during the course of beach recovery to determine whether erosional scarp height recovery is influenced by scarping height. The study also considered whether vegetation influences the recovery process through slumping.

This study aims to determine whether scarp height influences the length of time taken for scarps to recover through slumping on a short term scale, whilst longer term recovery processes such as berm accretion occur. Therefore the study investigated to whether higher scarps took longer to recover than smaller scarps. Scarping was investigating through visual examination of immediate post-storm LiDAR obtained by the University of New South Wales for the office of Environment and Heritage. Further, a recovery LiDAR capture was undertaken in November with scarping visually examined. The two LiDAR sets were then compared through production of LiDAR derived profiles, to determine differences in scarp shape and height through time. RTK GPS surveying was also utilised to examine scarp recovery through showing monthly change for a 5 month recovery period and supplemented photographic visual comparison to examine this aim. This was complemented with vegetation assessment to determine if a trend exist between vegetation present on scarping and the rate of recovery.

The results of this investigation showed that higher scarps did retain a vertical cut and higher height for a longer period of time during the recovery process. Moreover a possible trend was identified that shrubs including *Acacia var. sophorae* and *Leptospermum laevigatum* influenced scarp shape, with a higher vertical cut retained for a longer period. This study showed that investigation of scarp height, a major erosional impact of storms, has been largely understudied. LiDAR derived profiles and Digital Elevation Model maps provide an accurate and detailed morphological view of storm impacts and subsequent recovery. LiDAR is costly to acquire, however coastal managers should utilise this emerging technique to investigate large storm events to generate a catalogue of accurate spatial data to allow a standard when examining highly erosive event impacts to be tracked and future impacts to be predicted with storm frequency increasing due to climate change.

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Foredune Response to Storm Erosion and the Role of Vegetation in Recovery

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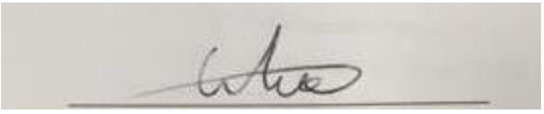
The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise for any other degree or qualification.



Christopher John Virtue

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Cover photo: Werri Beach looking north 22 November 2016. Photo by Christopher Virtue

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Erosional scarping of beaches as a result of the June 6th 2016 storm event provided an opportunity for coastal managers to increase knowledge regarding the impacts of large storm events on beach-dune systems. The recovery of scarps through slumping has not been widely investigated, with previous studies focused on beach response to storm events as an overview. The Illawarra and south coast region was examined during the course of beach recovery to determine whether erosional scarp height recovery is influenced by scarping height. The study also considered whether vegetation influences the recovery process through slumping.

This study aims to determine whether scarp height influences the length of time taken for scarps to recover through slumping on a short term scale, whilst longer term recovery processes such as berm accretion occur. Therefore the study investigated to whether higher scarps took longer to recover than smaller scarps. Scarping was investigating through visual examination of immediate post-storm LiDAR obtained by the University of New South Wales for the office of Environment and Heritage. Further, a recovery LiDAR capture was undertaken in November with scarping visually examined. The two LiDAR sets were then compared through production of LiDAR derived profiles, to determine differences in scarp shape and height through time. RTK GPS surveying was also utilised to examine scarp recovery through showing monthly change for a 5 month recovery period and supplemented photographic visual comparison to examine this aim. This was complemented with vegetation assessment to determine if a trend exist between vegetation present on scarping and the rate of recovery.

The results of this investigation showed that higher scarps did retain a vertical cut and higher height for a longer period of time during the recovery process. Moreover a possible trend was identified that shrubs including *Acacia var. sophorae* and *Leptospermum laevigatum* influenced scarp shape, with a higher vertical cut retained for a longer period. This study showed that investigation of scarp height, a major erosional impact of storms, has been largely understudied. LiDAR derived profiles and Digital Elevation Model maps provide an accurate and detailed morphological view of storm impacts and subsequent recovery. LiDAR is costly to acquire, however coastal managers should utilise this emerging technique to investigate large storm events to generate a catalogue of accurate spatial data to allow a standard when examining highly erosive event impacts to be tracked and future impacts to be predicted with storm frequency increasing due to climate change.

Contents

1. INTRODUCTION

Beaches along the Australian coastline are intrinsically imbedded within the social identity and culture of the nation as a result of widespread recreational and residential use. Beaches hold high ecological value through the provision of ecosystem services supporting a diverse range of flora and fauna. The Australian coastline concerns numerous stakeholders across more than 10 000 beaches. A comprehensive knowledge of core processes and issues within beach systems and the coastal zone are required by managers in order for proper management to address current coastal impacts and issues arising in the future. Dune systems play an integral role in the coastal setting through acting as a protective buffer zone to infrastructure and assets including road services and dwellings from potential storm damage associated with storm surge.

The extensive population pressure placed on beaches with 50% of the Australian population living within 7km of the coastline (Chen and McAneney 2006) creates sustained pressure on the coastal environment. Coastal management and an expansion of knowledge surrounding processes operating on coasts is essential to protect current and future coastal interests such as protecting recreational use and infrastructure found on the coastline. These issues will become increasingly relevant and important for coastal populations and the resulting human impact on the environment. To effectively manage the coastal environment in New South Wales, the NSW Office of Environment and Heritage utilises Coastal Zone Management Planning (CZMP) in conjunction with the Coastal Management Act (2016) which is replacing the Coastal Protection Act (1979) to address coastal hazard issues such as coastal inundation.

Through less reactive policy making, pressures on coastal ecosystems are reduced by balancing pre-emptive hazard identification with management outcomes to address all stakeholder needs, allowing better protection of the coastal environment.

With increasing storm activity and exacerbated impacts of sea level rise due to catastrophic human induced climate change, the nature of storms and their effect on the coastline needs to be consistently assessed to enable coastal managers to have a detailed record of events. This knowledge will allow for coastal managers to to better plan for storms and their subsequent impacts into the future. Through utilisation of currently available technologies such as LiDAR to assess impacts of storms including erosion scarps, managers can better assess recovery methods and explore suitable preventative methods to reduce storm impacts such as sea walls.

1.1 Background

Coastal management globally is an increasingly relevant area of political concern due to increasing coastal development and populations in the coastal zone. Understanding coastal processes which influence beach morphodynamics in an effort to make more informed management decisions regarding the coast has been highlighted by numerous storm events, notably the 1970's series of highly erosive storms. Due to extensive asset damage resulting from the storms, legislation to shape management of the coast such as the Coastal Protection Act (1979) was introduced with an aspect of this legislation prepared to inform management to combat storm impacts and foster cost efficient, effective recovery strategies.

An increased awareness of climate change in political and public settings has resulted in environmental impacts associated with predicted changes of sea level rise for coastal communities becoming a high concern in Australian and international contexts. The Fourth Assessment Report produced by the Intergovernmental Panel on Climate Change (IPCC) (2007) concluded with very high confidence that global average warming of Earth's climate attributed to anthropogenic sources has occurred since 1750, with a projected future temperate rise of 0.2 ºC every decade for the next century in conjunction with increasing Greenhouse gas emissions. The report also highlighted that projected sea level rise for 2090-2099 to be in the magnitude of 0.18-0.59m depending on the scenario (IPPC 2007).

The Fifth Assessment Report (5AR), also produced by the IPCC, concluded it is 'very likely' the mean global average sea level rise was 1.5-1.9mm/yr between 1901 and 2010 with a 2.8 to 3.6 mm/yr rise between 1993 and 2010. Predicted global mean sea level rise for 2081-2100 is estimated to be 0.26m-0.82m. The predicted sea level rise will adversely affect coastal systems and low-lying areas, and it has been stated with high confidence that regardless of temperature stabilisation, sea level rise will continue for centuries (IPCC 2014). This associated sea level rise with mean temperature increase is accompanied by very high confidence that coastal populations and assets including fisheries and tourism will be exposed and threatened due to coastal risks from increased waves and storms (IPCC 2014).

Therefore, Australian Local, State and Federal Governments are faced with a duty to plan for projected sea level rise for wide-scale asset protection (housing, roads etc.) and environmental protection to ensure minimal coastal infrastructure damage. There has been a large scale discussion regarding the impacts of sea level rise including infrastructure and property damage due to erosion (Zhang et al. 2004), increased coastal flooding due to the increasing storm surge height, thus decreasing the effectiveness of the buffer zone provided by the beach and dune system (Walsh, et al. 2004). As a result of the nature of these issues occurring during the lifetime of pre-existing infrastructure and associated necessary replacement of infrastructure; (impacts will likely begin to be realised within the next 20 years) (Walsh, et al. 2004) it is of high importance and urgency to begin forming policies and infrastructure planning to consider and mitigate these effects.

In Australia coastal management has been emphasised with importance from the 1970's when severe storms impacted upon the East coast of Australia resulting in severe damage and property destruction, highlighted with the most severe storm occurring in 1974 (See McLean and Thom (1975)). Cyclic processes of erosion and accretion and their influence upon beach morphodynamics are essential to successfully manage the coastal system. By continuing coastal process studies to better understand how erosion can threaten coastal infrastructure such as undercutting walkways and dune fences with sea-level rise threats, current management strategies will become increasingly effective to mitigate these threats.

1.2 Research Aims and Objectives

The aim of this project is to provide the Office of Environment and Heritage with information regarding the influence of vegetation present on post storm scarping and the elevation of the scarp during the recovery process. Due to the increasing storminess and sea level rise, understanding how vegetation influences scarping and recovery is important to inform future dune management strategies post highly erosive and destructive storm events.

1.3 Purpose and Scope of Study

The primary purpose of this study is to investigate whether there is a trend between the height of dune scarping and the length of time taken for the scarp to recover through slumping. This is examined through LiDAR derived digital elevation models (DEM) and RTK GPS surveying showing elevation change of the beach-dune system post June 6th 2016 storm event. The secondary purpose is to investigate vegetation present along dune scarping to determine if there is a trend between vegetation present and the height of scarping.

2. LITERATURE REVIEW

This chapter aims to explore the relevance of this study within the greater context of relevant literature. The chapter begins by discussing climate change and its causes and implications for the NSW coast through impacts such as sea level rise. Beach morphodynamics are then examined to outline cyclical processes occurring on the NSW coastline, followed by examining dune systems in NSW and their key characteristics. The chapter then examines storm impacts upon the NSW coast with case studies surrounding significant storms in 1974 and the June 6th 2016 storm event. Finally coastal management and governance of the coast is considered and its importance for the coastal region.

2.1 Climate Change

Climate change has increasingly become an issue of high international importance due to the substantial evidence produced indicating the potentially serious and destructive consequences highlighting that it is a substantial global challenge to overcome. The Intergovernmental Panel on Climate Change (IPCC) defines climate change to include any variation in climate whether human activity induced or naturally occurring (IPCC 2014). Several assessment reports have been created including the most recent report; the Fifth Assessment Report (5AR), which have been compiled to establish and increase knowledge regarding observed climate change, natural and human drivers of this change and projected climate change.

2.1.1 Observed Climate Change

Warming of Earth's climate is consistently happening as evident through observations of increasing ocean and air temperatures, sea level rise and the melting of ice sheets (IPCC 2014). The IPCC has concluded it is likely that 1983-2012 was the warmest 30 year period for the past 1400 years in the northern hemisphere, with global average combined sea surface and land temperatures showing a linear trend of warming 0.85 °C (0.65 to 1.06°C error margin). On a global scale, it is "virtually certain" the upper ocean (0-700m) warmed from 1971-2010, with ocean warming being greatest near the surface (75m) by 0.11 (0.09-0.13) °C (IPCC 2014).

2.1.2 Drivers of climate change

Climate change of the earth's climate system has and continues to be altered by the concentration variation of aerosols and several important greenhouse gases including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The largest increase in atmospheric concentrations of greenhouse gases has been caused by anthropogenic release of emissions during the industrial era (1750 and 2011) with anthropogenic carbon dioxide emissions to the atmosphere of 2040 ± 310 $GtCO_2$. 40% of these emissions have remained in the atmosphere whilst 30% has been absorbed by the ocean resulting in increased acidification, with half of the emissions during this period occurring between 1971 and 2011 as seen in Figure 1 (High confidence)(IPCC 2014).

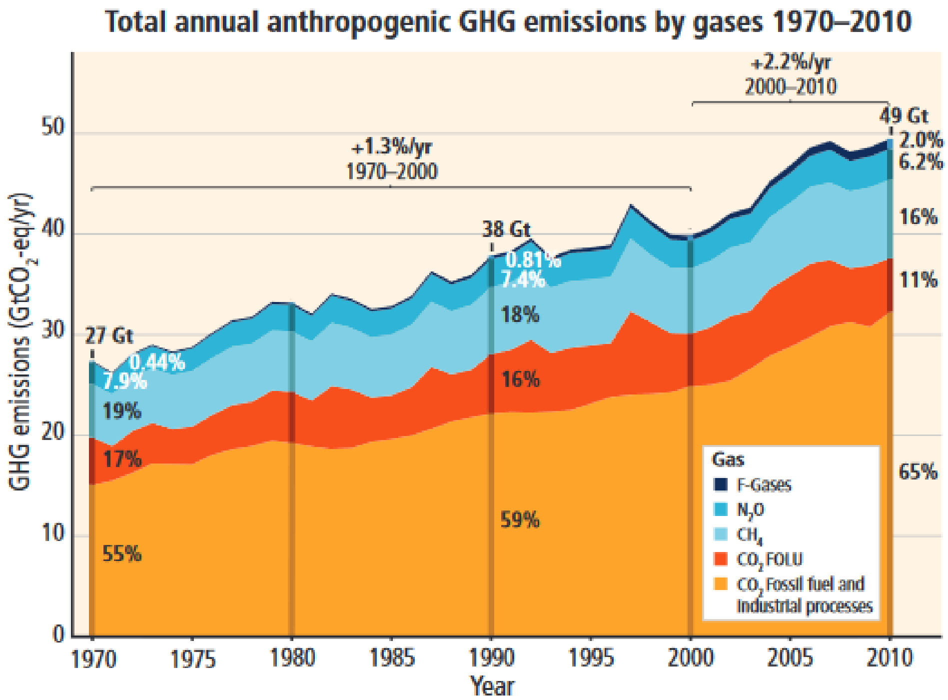


Figure 1. Anthropogenic Greenhouse Gas Emissions 1970-2010 (Source: IPCC, 2014)

Carbon dioxide is primarily emitted to the atmosphere through fossil fuel use since pre-industrial periods, with land use through farming and other associate pursuits contributing to the other smaller contribution of CO_2. Methane atmospheric concentrations have also increased within this period due to fossil fuels use and agriculture.

2.2 New South Wales Beach-dune Systems

New South Wales beach systems are of high importance for numerous stake holders including residents, recreational users and coastal managers; hence extensive study has occurred particularly in Moruya and Narrabeen. Short (1999) produced The Handbook of Beach and Shoreface Morphodynamics detailed and described different beach types which are broadly divided into wave-dominated and tide-dominated. Wave-dominated beaches are exposed coastal beaches which are subject to ocean swell and waves consistently, whereas tide-dominated beaches occur in areas such as large bays with low wave conditions and consistent tide conditions.

Within the beach-dune systems of NSW, sandy wave-dominated beaches are of high prevalence. Beaches generally begins offshore, extending landwards to include characteristics of the system including nearshore bars, surf zone, berm and dune systems (Kidd 2001). The subaerial beach is affected by the swash and intertidal zone, followed by the surf zone where wave energy changes the shape of the sea bed and the nearshore zone in which eroded sand is deposited back on the beach in recovery periods (Short 2007). Aside from the subaerial beach where the berm is situated, the interacting dune system is of considerable importance to the coastal zone due to being considered an integral line of defence against the impacts of storms such as erosion and coastal inundation on infrastructure and services (Kidd 2001).

2.3 Beach Morphodynamics

2.3.1 Beach Classification

Beaches are classified along the NSW coastline into 6 types which range from reflective, through intermediate to dissipative beaches. Intermediate beaches are further divided into rhythmic bar and beach (RBB), transverse bar and rip (TBR) and low tide terrace (LTT). Longshore bar and trough (LBT) and dissipative beaches are not commonly found on the NSW coast as they occur where wave energy is higher. The beaches on this natural spectrum are classed upon the parameters of wave height, wave period (modal wave) and grain size (Short 1999). Sheltered beaches show little variation in beach type over time due to consistent wave conditions, whereas exposed beaches experience a far greater range of wave conditions and thus change states rapidly and are likely to erode more quickly (Short 2007).

Furthermore, each beach on this spectrum is assigned a value in accordance with the safety factor index. This index scales beaches according to hazards present (e.g. rocks, headlands, water depth, breaking waves) (Short 2007), with the ultimate system ranking beaches from 1 (safe beaches) to 10 (least safe/dangerous beaches). The safety factor is not of high importance for this study, however the classification is useful particularly for recreational users. The beach types are explored below examining the spectrum from lowest energy to highest energy beach types.

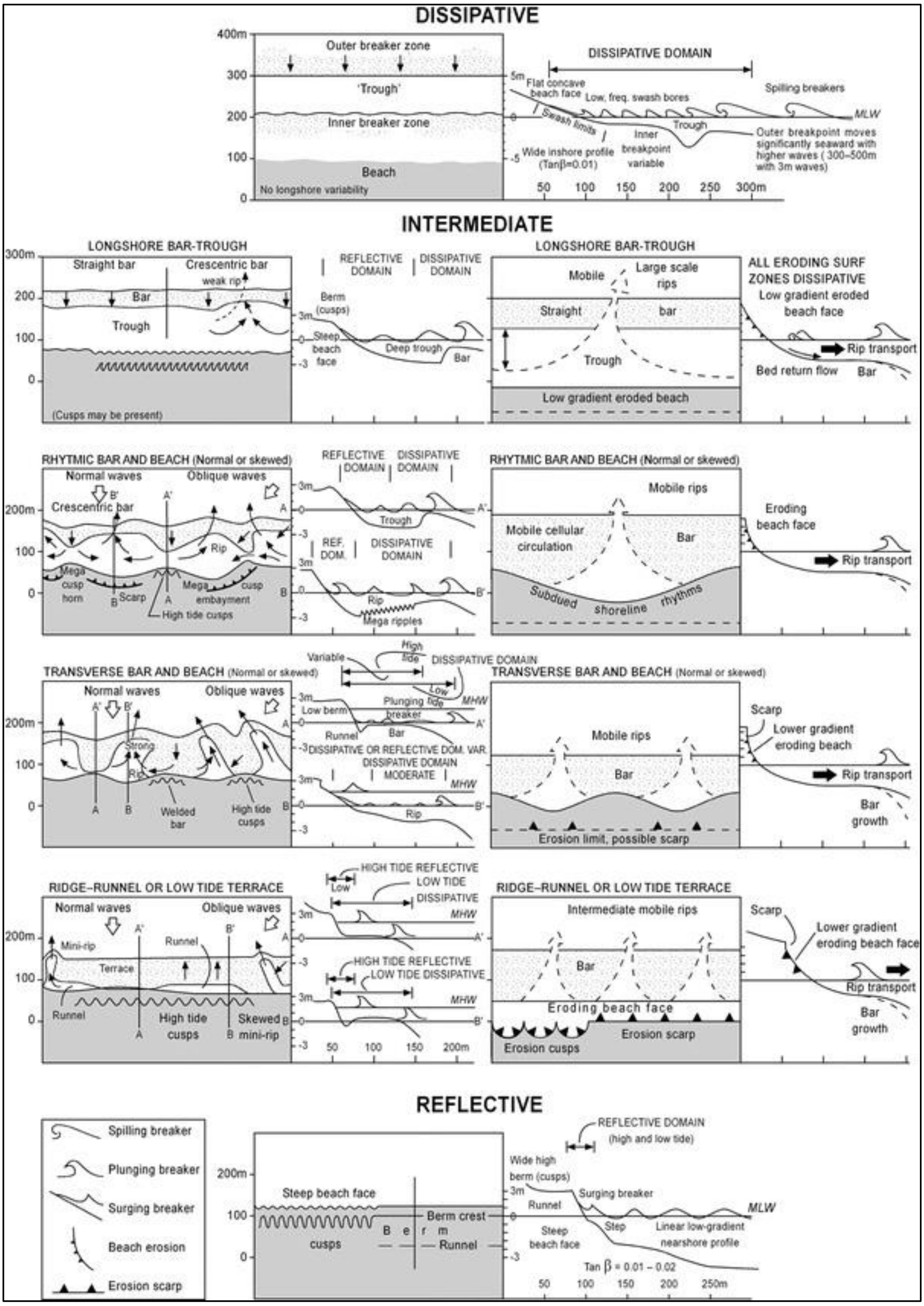


Figure 2 Wave Dominate Beach Types Ssequence for Accretionary (left) and Erosional (right) Conditions (Source: Short 1999)

Reflective beaches represent the lowest energy within the beach state, being characterised by narrow, steep beaches consisting of coarse sands and being subject to low wave height conditions. Within this beach type, cusps form on the subaerial beach face due to a lack of bars in the swash zone to break waves thus when they arrive at the shoreline, with waves reflected back. Due to the low wave conditions, hazards at these beaches are quite low and therefore have a low safety rating of approximately 2-3 out of 10 thus making them quite safe for recreational activities such as swimming (Short 2007).

Low tide terrace beaches (LTT) are the lowest energy intermediate beach type and therefore the safest for recreational activities. These beaches (also known as ridge and runnel) are characterised with a steep beach face (similar to reflective beaches) and have an attached bar to the shore which is cut by rips. The beach is considered one of the safest beach types with a safety rating of 3-4/10 and can only become dangerous when waves exceed 1m in height causing dumping waves and transient rips(Short 2007).

Transverse bar and rip (TBR) beaches are very common along the Illawarra and South Coast regions and indeed the NSW coast. Formation of this type occurs with bars forming perpendicular to the shore and are attached to the shoreline. Short (2007) asserts this beach type provides the NSW the exemplary surf conditions for recreational surfing and swimming, however due to the bar having rips in close proximity and plunging breaking waves, this contributes to peril for swimmers thus this beach type has a safety rating of 5/10.

Rhythmic bar and beach (RBB) beaches exemplify the highest transitional beach type that commonly occurs in the NSW coastline context. It consists of rhythmic bars and shorelines, with continuous strong rips, deep channels, plunging waves and rip feeder channels thus being considered the least safe intermediate beach with a rating of 6-7/10 (Short 2007).

Longshore bar and trough (LBT) is another very uncommon high energy intermediate beach type and is characterised by a continuous longshore bar separated by a deep trough. This beach is quite dangerous for recreational activities due to the rips that cross the bar and currents giving the beach a rating of 7-8/10 (Short 2007).

Finally, *dissipative* beaches exemplify the highest energy beach type for wave dominated beaches and are rare on the NSW coast due to the formation conditions required of very big seas such as during and post-storm activity. This beach type is highly dangerous due to very strong breaker waves, large wave height and rips therefore having a rating of 9/10 and being the most dangerous beach on the continuum (Short 2007).

2.2.2 Beach Studies undertaken in NSW

Scientific research based on NSW beach systems such as Short (1988, 1993, 1999, 2006), Bryant (1983,1988,1980), Short and Hesp (1982) and Clarke and Eliot (1983, 1988) have examined beach processes demonstrating differing, fluctuating coastal systems. Table 1 highlights a summary of coastal literature produced by Baker (2006).

Table 1 Summary literature of coastal research and management implications (Baker 2006)

Beach Environment	Author/ authors	Time Period of Study	Techniques/ methodologies	Significant Findings	Management Implications
All of NSW beach systems as part of the NSW beach safety and management program.	Short (1993).	-	Assigned beaches to a safety rating and beach type classification.	Information on beach type, safety rating, amenities, boat ramps, swell conditions, access facilities, surf clubs, name and location.	Provides an overview of coastal infrastructure and a beaches recreational potential.
Stanwell Park Beach	Bryant (1983a, 1983b, 1988).	1890-1980 and 1943-1978	Oblique and vertical aerial photographs.	Identified periods of beach erosion and accretion and established links to factors such rainfall, storminess over previous year, the SOI and sea-level.	Identified contributing factors to beach erosion and concluded a relatively stable shoreline position.
Narrabeen Beach	**a)** Short (1985), **b)** Wright et al (1987), **c)** Short and Trembanis (2004) and **d)** Ransinghe et al, (2004).	**a)** 1976-1977 **b)** 1977-1978 **c)** 1976-2002 **d)** 1976-2000	**a)** Rip and swell observations **b)** wave and tidal data **c)** monthly beach profiles and **d)** monthly beach profiles and image processing.	**a)** Identified rip type and spacing **b)** wave and tide influence of beach state **c)** beach rotation and Oscillation and **d)** the role of the SOI wave climate on beach rotation.	Identified that beach rotation occurs in response to the SOI, and that intensified future El Nino events will enhance beach rotation.
Moruya Beach	**a)** Thom and Hall (1991), **b)** McLean and Shen (2006).	**a)** 1972-1988 **b)** 1972-2006	Monthly beach profiles.	Identified beach erosion and accretion dominated periods and foredune development.	Identified contributing factors to beach erosion such as the 1974 storm event and concluded a relatively stable shoreline position.
Warilla Beach	**a)** Eliot and Clarke (1982) **b)** Clarke and Eliot (1988a, 1988b).	**a)** 1975-1980 **b)** 1965-1983 (a) and 1975-1985 (b).	**a)** Fortnightly beach profiles **b)** weather records and fortnightly beach profiles.	Identified cycles of sediment movement along and across the beach face.	Identified contributing factors such as weather systems, storm events and beach processes (rips) to beach sediment movement such as beach erosion.

2.3. Dune Systems

Dune systems are an important coastal feature through acting as an valuable natural line of defence against storm impacts and erosive conditions. A cross-section of NSW wave-dominated beach-dune systems highlights the grading vegetation zone including the incipient dune, foredune and hind dunes (Figure 3)

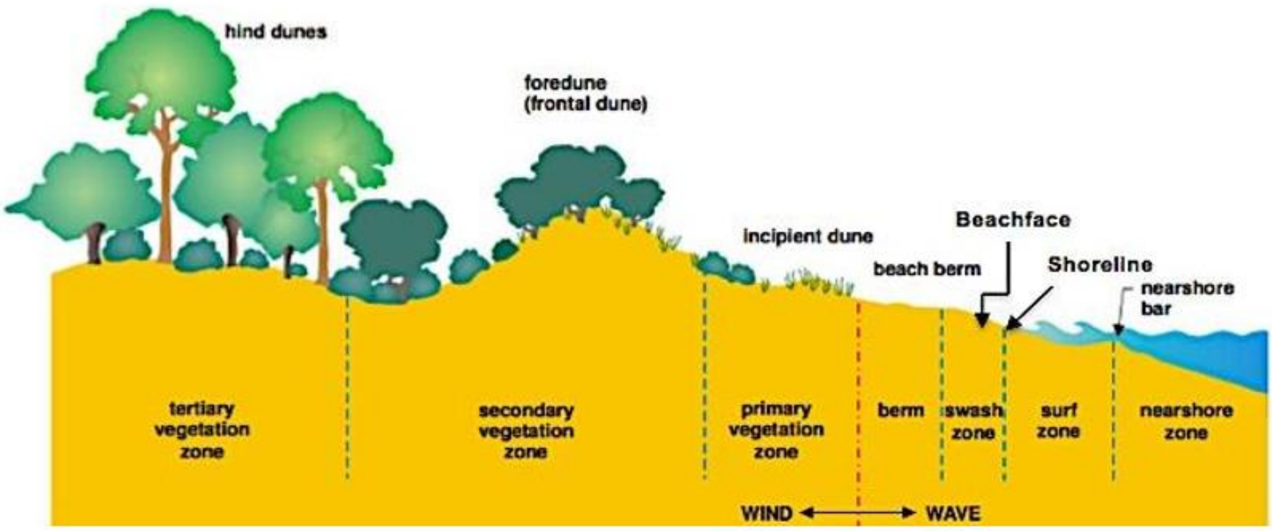


Figure 3 - Cross section of an idealised natural NSW wave dominated beach dune system (Kidd 2001)

2.3.1 The incipient foredune

The incipient dune (Figure 3) is the first zone of the dune system which is considered the developing dune with pioneer vegetation trapping sand to form a foredune with excess sand accumulation, and is the first zone to be impacted upon in highly erosive events often resulting in complete removal of the zone (Kidd 2001). New or developing foredunes within pioneer plant communities, may be formed by sand deposition within discrete clumps of veg, individual plants, driftwood forming shallow dunes, mounds and nebkha (vegetated sand mound formed when veg inhibits drifting sand) (Hesp 2002). Incipient foredunes may initiate in a seasonal manner where formed around annual plants (grow annually at certain times) and require perennial plants (grow all year) to invade to facilitate survival, whilst forming in various locations from the backshore to the back barrier flats (Hesp 2002). Also, incipient dunes may form on the backshore through laterally continuous alongshore growth of pioneer vegetation seedlings (Hesp 2002). During the formation of incipient dunes, plant species present is integral in determining morphological development. An example of this is seen through the species *Ammophilia* (exotic) which produces higher, more hummocky dunes in comparison to *Spinifex sericeus* (native) dominated areas which produce lower, less hummocky dunes (Hesp 2002). Within this zone it is important to note that morphological development primarily depends upon plant density, height, distribution, cover, wind velocity and sediment transport, whilst secondary factors such as storm erosion, overwash and swash inundation determine subsequent dune evolution. Sediment transport is affected by beach width, temporal variations in sediment supply, wind approach direction, seasonal climatic variations, lag development, water table height (Hesp 2002). These factors therefore contribute to the hypothesis that as plant height increases, dune height increase and dune length decreases (Hesp, 1988). This is the primary aim of this study which is being examined.

Incipient foredune morphologies generally exhibit 1 of 3 forms

- <u>Ramps:</u> Form when 1) seedlings germinate on a seaward sloping backshore; 2) plants trap sand from a landward source on a seaward sloping berm or backshore; 3) where plants germinate or grown on scarp fill or at base of scarp which gradually accretes
- <u>Terraces:</u> Form when 1) rapid plant growth takes place across backshore (particularly on rapidly accreting beaches); 2) seaward plant growth roughly matches accretion rate; 3) plants grow across or on a backshore that experiences little accretion
- <u>Ridges:</u> Form when 1) accretion rates are relatively rapid and sand deposition occurs in seaward portion of plant canopy; 2) plant density and height is high; 3) seaward growth rates are slow relative to accretion; 4) wave scarping of foredunes

2.3.2 Foredune

The foredune area is regarded as an established incipient dune and can be defined as "shore-parallel dune ridges formed on the top of the backshore by Aeolian sand deposition within vegetation"(Hesp 2002). The foredune, also called a frontal dune is normally characterised by having a high morphological elevation and contains intermediate height plant species, predominantly shrubs (GHD 2014). These species are often woody plants with greater complexity, height width, age and geological position (Hesp 2002). Evolution of foredunes is dependent on several factors including: sand supply, degree of vegetation cover, vegetation species present, rate of accretion and erosion, frequency and magnitude of wind and waves, storm erosion and scarping, medium to long term beach or barrier state, water level and human influence (Hesp 2002).

Foredunes range in size from very low scattered dunes <1m in height to large dune complexes 30-35m in height. Low dunes occur globally on some barrier islands (none in Australia) with overwash dominating. Large dunes are rare and occur on coasts prone to erosion where human impacts have occurred to artificially induce greater height e.g. beach nourishment, with sand accumulating at dune base. Therefore it must be noted foredune height and volume is related to beach-surfzone type (Short and Hesp 2002). It has been noted that larger foredunes commonly occur on dissipative beaches whilst smaller ones occur on reflective beaches (Hesp 2002).

2.3.3 Hind Dune

The hind dune is the most landward section of a dune system and is an accumulation of older foredunes. The vegetation of this area is predominantly well established vegetation such as forests and trees. Many NSW beach systems however have housing and infrastructure built upon the hind dunes which may influence the system.

2.3.4 Factors influencing Foredunes

Hesp (2002) has suggested sea level rise will impact considerably on dunefield initiation or response. Human influences upon the dune systems are of significance due to activities such as grazing, sand mining, sand extraction, access to the beach unregulated and protection measures such as sea walls and residential development influencing the system to exacerbate processes such as sand drift, infestation of exotic species, erosion and inundation (Brewer and Whelan 2003). Influence is also seen through fencing of dunes and walkways to enable vegetation growth.

Impacts of sea level rise are seen through beach width decreasing depending on the increase in sea level and surfzone type. Further impacts include (adapted from Hesp (2002))

a) Foredune slope erodes, blowouts develop with crest of dune increasing in height and moving landward
b) Foredune Scarped with destabilisation forming blowouts
c) Sediment supply significant and progradation still occurs

2.3.5 Impacts of Dune blowouts:

Blow outs are a saucer/cup/trough shaped depression formed by wind erosion. Morphology is highly variable, with a large degree of spatial and temporal variability in blowout morphology. Blowouts are initiated by wave erosion, topographic acceleration of airflow over dune, climate change, veg variation, water erosion, high velocity wind and human activities. Where scarping is present, blowouts can be initiated (Hesp 2002). This was not noted during field studies conducted at the study beaches.

2.4. Impact of storms, East Coast Lows and processes of recovery

Beach systems are dynamic with continuous morphodynamic change attributed to waves, tides and winds (Karunarathna, Pender et al. 2014). Major storm events generate high wave conditions resulting in significant change and stresses on the beach face over a short term scale, as evident through significant and rapid morphological changes including severe erosion, instability of beaches and wave overtopping (Karunarathna, Pender et al. 2014).

After a severe storm, recovery of beaches is evident through the transportation of sand back to the shoreline during successive calm conditions from nearshore bars (Karunarathna, Pender et al. 2014). Whilst storm events occur rapidly with high levels of erosion of the berm and incipient foredune, recovery through the deposition and accumulation of sediment is a far more gradual process (Thom and Hall 1991).

The frequency and magnitude of storms upon the South-Eastern coastline of Australia has been linked with phases of the Southern Oscillation Index (SOI)(You and Lord 2008), with increased damage and coastal recession observed during La Nina phases as attributed to increased incidence of storm activity, whilst El Nino years have low levels of damage with beach recovery more prominent (You and Lord 2008). Moreover, the SOI has been linked to beach rotation which refers to variation in beach profile along the extent of the beach (Short and Trembanis 2004). Long term recession of the coastline can be the result of sea level rise or sediment imbalance (Callaghan, Roshanka et al. 2009) and requires further quantification of factors which influence beach morphology including the behaviour and extent of offshore sand bars(Wainwright, Ranasinghe et al. 2014).

The New South Wales Coastline is impacted upon by large wave events and wave conditions generated by storms and the scale of impacts on the beach system depends upon several variables; beach location, beach aspect, wave refraction processes, human influence and beach size and type(Bryant and Kidd 1975).

The predominant impacts of storm events upon the NSW coastline and beach include lowering of beach face, erosion of backshore and berm producing vertical scarps cut into the incipient foredune and landward shoreline retreat(McLean, Shen et al. 2010).

East Coast Lows refer to intense low-pressure systems characteristically developing off the east coast of Australia and can occur over a range of times during the year with maximum frequency occurring in June(BOM 2007). They are known to intensify overnight, with formation in summer occurring from being ex-tropical cyclones whilst during other times of the year, occur rapidly within a pre-existing low pressure trough. ECLs are driven by the temperature gradient between the Tasman Sea and Cold air in the atmosphere producing unfavourable conditions including heavy rainfall, coastal inundation (storm surge) and gale force winds.

2.4.1 Moruya 1974 case study:

The Moruya storm event of 1974 severely impacted beaches along the southern and central NSW coastline with a storm recurrence interval of 1/100 year (Bryant and Kidd 1975, Lord and Kulmar 2001). The east coast low became stationary over the coastline attributed to the unseasonably warm Tasman sea causing highly erosive wave conditions for several days which was also exacerbated by unusually high tide conditions(Bryant and Kidd 1975). A study conducted by Bryant and Kidd (1975) examined the effect of the storm upon the south and central NSW coast beaches and the associated beach damage and erosion. The study found that large exposed beaches could withstand erosive conditions in a more effective manner rather than smaller pocket beaches, due to large beaches being able to adjust and absorb a larger range of waves associated with the storms compared to the smaller pocketed beaches (Bryant and Kidd 1975).

Moreover, it was found that spatial confinement played a significant role in small pocketed beaches losing a greater proportion of their backshore in the process of attaining an equilibrium profile; with severe erosion of sheltered beaches such as Manly cove due to wave refraction and concentrated wave energy whilst exposed beaches minimised eroisional impacts due to adjustment to refracted south easterly swell (Bryant and Kidd 1975). The storm also highlighted that metropolitan beaches along the coastline such as Manly had high erosion due to sea wall limiting the foredune sand compartments in conjunction with sea walls enhancing erosional capacity of waves attributed to reflection processes operating.

2.4.2 Strategies to mitigate Impacts of Storm

Storm management in the next century with sea level rise is of great importance to coastal managers globally, due to 10% of the world’s human population living along the coastline, with 77% of the global economic output and 2/3’s of the world’s megacities to be contained by coastal regions .

Impacts of storms are predominantly seen through inundation due to storm surge which has the ability to severely damage coastal infrastructure (Zhang, 2004). Moreover, erosion of the beach-dune system resulting in significant scarping is a prevalent issue faced by coastal managers.

Due to inundation and erosion, infrastructure may be damaged and ecosystems destroyed irreparably (Feagin, et al. 2015). There has been a shift in research strategies surrounding nature based solutions, shelter belts or bioshields, ecological restoration and ecological engineering as management strategies. Vegetation based solutions such as reshaping and revegetating dunes are gaining momentum as a strategy for asset protection against extreme storm due to cost efficiency, whilst responding to coastal processes on short term (seconds to days) and long term (years to millennia)(Feagin, Figlus et al. 2015).

Short term disturbances upon dune systems are seen through dramatic and rapid actions such as nearshore scouring, shoreface erosion, flooding, flattening of dunes, barrier breaching and overwash with sand deposition at landward locations.

2.4.3 Vegetation Management

Vegetation modifies dunes before during and after storms to provide a cost effective solution for coastal asset protections utilising dunes. Before storms plants modify the dunes through acting as a wind barrier to accumulate sand, add organic matter and trap fine inorganic sedimentary particles to reduce erosion. During storms plants alter hydrodynamics with above and belowground plant structures likely altering wave energy and flow during storms, but limited research indicates vegetation reduces erosion(Feagin, Figlus et al. 2015). Aboveground veg increases friction encountered by water, therefore reducing the wave energy that would propagate landward. After storms plants influence the dune building process; early successional plants recolonise bare areas (native species can extend range due to event) thus stabilising dunes and fostering recovery(Feagin, Figlus et al. 2015). Criteria for plant management have been outlined by Feagin et al (2015) and are of significance for coastal managers.

Table 2 Plant based management criteria (Feagin et al 2015)

Table 1. Management considerations for the use of vegetation species as protection on high-energy shorelines

Choose plants as modifiers of geomorphic features based on their ability to:

- Accrete sand/build elevation
- Develop high dunes versus low hummocks
- Fit within a heterogeneous array of different successional stages, with effects on landscape form

Choose plants as modifiers of soil stability based on their ability to:

- Add soil organic matter and increase water content, reduce soil bulk density
- Promote mycorrhizae, increase effective grain size of non-cohesive particles
- Promote clay and cohesive particle accumulation
- Incorporate layering of algal and other beach wrack

Choose plants as structures that alter storm hydrodynamics based on their ability to:

- Attenuate waves and alter water velocities according to: stem height, diameter, flexibility; leaf area; overall plant architecture; aboveground biomass
- Reinforce, abrade, or loosen soils according to: root diameter, configuration, and density; belowground biomass; aboveground-to-belowground biomass ratio

Choose plants as modifiers of storm recovery based on their ability to:

- Physiologically respond to storm erosion according to: damages to plant structures or compensatory stimulation of growth; sexual (seeding) versus asexual (uprooting of rhizomes) modes of reproductive spread
- Provide protection for humans via their physiognomic form; potential to also become invasive, alter habitat diversity, and increase or decrease long-term ecosystem resilience

2.4.4 Storm Clustering

Storm Clustering is another aspect of high importance for coastal management as it can exacerbate the impact of storms upon the coastline, evident through multiple successive storms causing highly erosive conditions (Karunarathna, Pender et al. 2014). Succeeding storms are of greatest impact upon the coastline altering the beach face and eroding foredunes to produce scarping when the period between storms is insufficient for recovery (Karunarathna, Pender et al. 2014). A study conducted into storm clustering undertaken by Karunarathna et al (2014) on Narrabeen beach over 20 years found that storms concetrated in a short period of time (e.g 1974 storms) generated more extreme erosion and associated impacts whilst storm cluster erosion resembled erosion consisten of a single storm of higher intensity and greater return periods (Karunarathna, Pender et al. 2014).

2.4.5 *El Nino and Southern Oscillation*

The Southern oscillation is also of importance in the coastal management. El Nino and the Southern oscillation index are inextricably linked. It has been studied and found that long term induced erosional phases on the coast of NSW are linked to the Southern Oscillation Index (SOI)(Callaghan, Roshanka et al. 2009);(Short and Trembanis 2004). Due to the higher frequency of tropical cyclones and east coast lows during the La Nina phases rather than El Nino, coastal recession and damage is more frequent during La Nina phases whilst recovery and lesser coastal damage can be expected during El Nino years(You and Lord 2008).

Moreover, the investigation undertaken by Ranasinghe, McLoughlin et al. (2004) investigated erosional processes and SOI at swash dominated pocket beaches, finding during early stages of El Nino and 3 months after the SOI minimum, south westerly swell waves caused northern ends of the study beaches to accrete more than the southern end, with higher erosion at the southern end (Ranasinghe, McLoughlin et al. 2004). The net accretion at the northern end of the beach and net erosion at the southern end of the beach resulted in a clockwise rotation of the beach (Ranasinghe, McLoughlin et al. 2004), but due to the relatively low frequency of storms in El Nino, they do not play a major role in influencing rotation at this phase compared to the La Nina phase where storms in this phase are double the amount of El Nino (Ranasinghe, McLoughlin et al. 2004).

The La Nina phase produces double the amount of erosion at the northern end compared to the southern end attributed to storm activity and offshore sediment transport from north easterly waves thus resulting in southward longshore currents and sand deposition at the southern end (Ranasinghe, McLoughlin et al. 2004). The net accretion at the southern end and net erosion of the northern end during the La Nina phase results in anticlockwise beach rotation (Ranasinghe, McLoughlin et al. 2004).

2.4.6 Post storm Recovery

Beaches undergo post storm-recovery in which sediment accretion occurs due to onshore sediment transport in calm conditions (Thom and Hall 1991). Major erosional periods such as the Moruya 1974 storm have periods of sediment accumulation to produce and foster the re-establishment of the foredune and berm thus producing a more stable shoreline position (Thom and Hall 1991). The recovery period after storms sees a reformation of the scarp through onshore wind mobilising sediment across the wide berm to be trapped when it reaches dune vegetation to reinforce incipient dune formation(Thom and Hall 1991). The role of vegetation is examined in more detail in the following chapters.

*2.4.*7 *Long term Recession*

Long term coastline recession is of high significance to the entirety of the coastal zone and all associated stakeholders. Two forms of coastline retreat are of importance for coastal managers; ephemeral coastline retreat or retreat associated with storm activity and chronic coastal retreat which is associated with sediment imbalance or sea level rise, a predominant impact of climate change(Callaghan, Roshanka et al. 2009). Whilst both need quantification for coastal management, it is difficult to determine where long term recession is occurring due to the dynamic nature of beach. Long term shoreline recession analysis has been conducted through examination of historical aerial photography in which recession is assessed by determining rates of change in cross-sectional areas of sand and features such as vegetation lines and scarps over a specified time period(Wainwright, Ranasinghe et al. 2014). This analysis provides coastal managers to use the determined rates of retreat in association with the production of hazard lines for future coastal planning(Wainwright, Ranasinghe et al. 2014). However whilst trends are identified, a lack of sufficient knowledge of processes driving trends thus means beach systems cannot be properly projected into the future (Wainwright, Ranasinghe et al. 2014).

Long term recession has been assessed by the use of the Bruun rule, which describes the cross-shore response of beaches to sea level rise (Bruun 1988) essentially stating that a beach profile will move upwards and landwards in response to sea level rise as a result of eroded sediment being deposited at the lower portion of the profile (Bruun 1988). The rule does not include processes such as longshore drift and assumes a closed material balance system thus limits its use in determining recession (Cooper and Pilkey 2004). Long term recession has also been assessed through the use of GIS to simulate recession trends, by basing projections on the Bruun GIS model to produce a cost effective and rapid approach to assess long term recession, however only producing an initial estimate for further concentrated study (Hennecke, Greve et al. 2004)

2.5.June 6th 2016 East Coast Low case study

The June 6th east coast low (ECL) of 2016 provided coastal managers a substantial challenge to address due to the highly erosive nature of the storm, which meant the event became highly publicised. The event began on the 3rd of June as a cold air mass situated over central

Australia interacted with an extended low pressure trough which formed and was situated over the warm Eastern Australian coastline. The ECL tracked down the Eastern coast of Australia in a southerly direction, having multiple low pressure centres with the closest centre producing high wind and heavy rainfall in conjunction with another centre further offshore to produce high north-easterly swell (Burston and Taylor 2016). The presence of a strong and near-stationary high pressure system over New Zealand maintained an airstream to the trough allowing consistent moist air to be fed into the low pressure system as shown in Figure 4.

Due to the nature of the storm and its slow tracking progress down the coastline, the event was characterised by high rainfall in excess of 100mm with a regional average for NSW of 73.11mm, large swell and strong winds. Table 3 highlights the strong winds and heavy rainfall experienced by the NSW coastline.

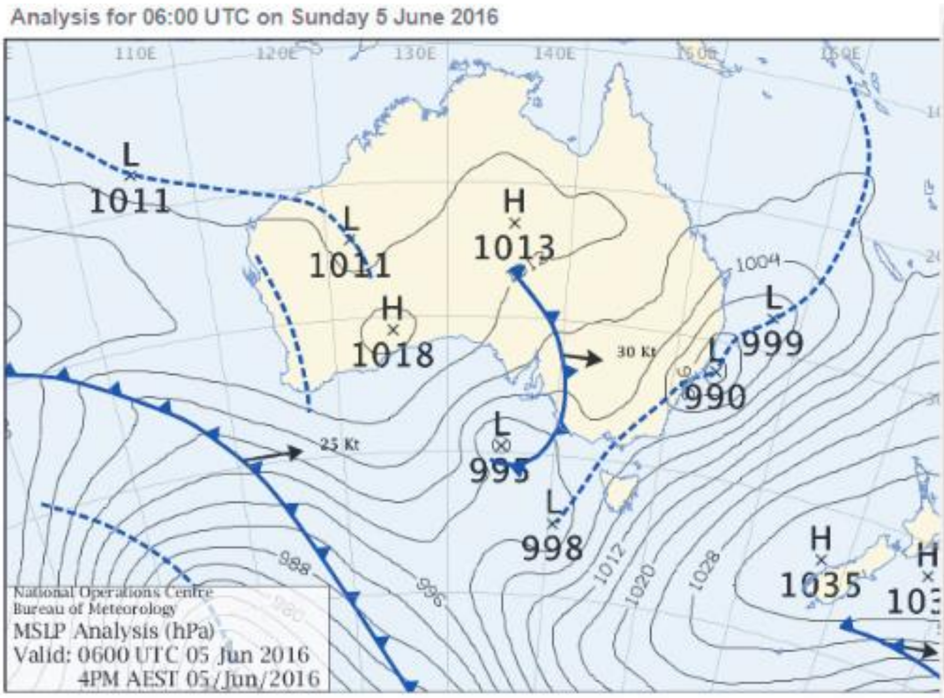


Figure 4. Synoptic Chart showing multiple low pressure centres of the ECL on June 5th 2016 (Source: BOM)

Site	Weekly Cumulative Rainfall (mm)	Max Wind Gust (km/h) (Direction)	Mean Surface Level Pressure (hPa)
Tweed Heads	438	78 (ENE)*	996.6*
Ballina	272	91 (ENE)	996.3
Coffs Harbour	263	85 (NE)	993.7
Port Macquarie	121	78 (NNE)	991.6
Foster	217	67 (NE)	-
Newcastle (Nobbys)	138	106 (ENE)	995.5**
Sydney Airport	236	98 (NE)	996.3
Wollongong	289	102 (ENE)	997.6
Batemans Bay	265	80 (ENE)***	996.3***
Bega	298	76 (NE)	997.4

*Coolangatta station ** Norah Head station *** Moruya Airport

Table 3. Summary of peak daily winds, atmospheric pressure and rainfall during the week period of the June 2016 ECL (Source: BOM)

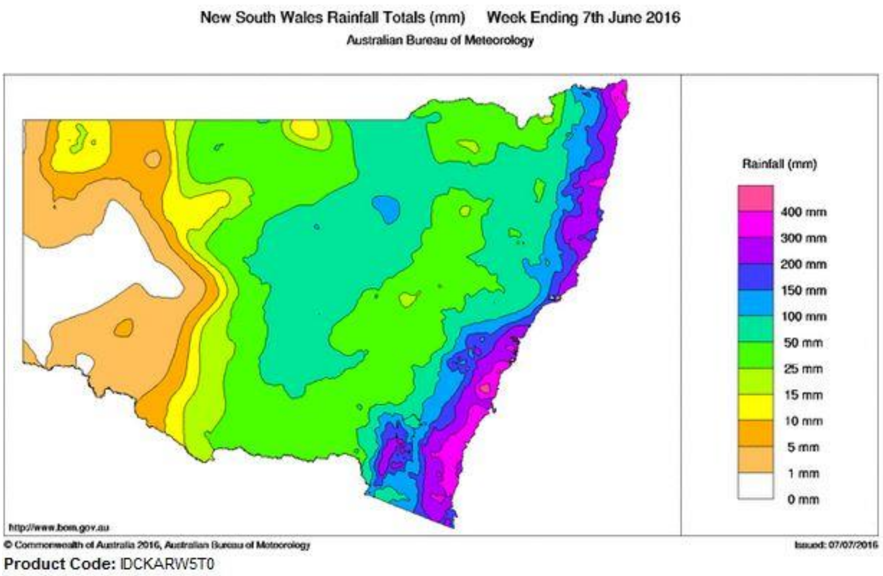


Figure 5. Synoptic Chart showing multiple low pressure centres of the ECL on June 5th 2016 (Source: BOM)

The event was of considerable media coverage and interest to the coastal stakeholders due to the coastal inundation and erosion impacts associated with the event. The coastal impacts of this event were exacerbated due to the coinciding of the ECL with a king tide, causing highly specific areas facing East to northeast directions to be severely affected due to the persistent wind and wave direction impacting upon embayments which are not frequently prone to large wave conditions (Burston and Taylor 2016). The peak water level for the event occurred on the evening of the 5th of June with the higher than normal levels persisting for the following three tides with a storm surge ranging from 0.43m to 0.17m (Burston and Taylor 2016). Table 4 highlights the ocean water levels and storm surge for the June ECL along the NSW coast. The wave heights were measure by wave-rider buoys situated approximately 10km offshore.

Table 4 Peak Ocean water levels and storm surge for June 2016 ECL on the NSW coast (data source MHL) Sourced from Burston and Taylor 2016

Site	Peak Water Level (m AHD)	Predicted Tide at Peak Water Level (m AHD)	Residual at Peak Water Level (m AHD)	Time of Peak Water Level (AEST)	Peak Tidal Residual (m)	Time of Peak Storm Surge (AEST)
Ballina	1.40	1.09	0.31	5/06/2016 20:30	0.42	5/06/2016 15:45
Yamba	1.22	1.05	0.17	5/06/2016 20:15	0.39	5/06/2016 11:30
Coffs Harbour	1.57	1.13	0.43	4/06/2016 19:15	0.48	5/06/2016 2:00
Port Macquarie	1.39	0.97	0.43	5/06/2016 20:30	0.75	5/06/2016 13:30
Crowdy Head	1.42	1.10	0.33	5/06/2016 20:00	0.56	5/06/2016 9:00
Shoal Bay	1.30	1.07	0.24	5/06/2016 21:00	0.34	5/06/2016 13:15
Sydney	1.29	1.08	0.20	5/06/2016 20:15	0.34	5/06/2016 13:45
Ulladulla	1.53	0.86	0.68	5/06/2016 20:15	0.68	5/06/2016 20:15
Batemans Bay	1.24	1.00	0.24	5/06/2016 20:30	0.56	6/06/2016 4:15
Eden	1.21	0.88	0.33	6/06/2016 21:45	0.42	6/06/2016 2:00

The water levels are not particularly out of the ordinary for ECLs with an ARI of less than 5 years at most areas however Batemans Bay had an ARI of 20 years (Burston and Taylor 2016). It is of importance to note that the waves produced an ARI of between 1 and 10 years for all sites, and due to the unusual nature of the storm producing east to north east wave directions, for this direction, the event exceeded the largest recorded wave height for this direction since measurement began in 1992 (Burston and Taylor 2016).

In summary, the event produced significant coastal erosion and inundation due to the slow tracking ECL moving southward along the NSW coastline bringing heavy rain, strong winds and high sea levels due to the event coinciding with a king tide. The unusual wave direction of east-north east exacerbated erosion impacts due to event predominantly affecting bays which receive little erosion. For this reason, the event received significant coverage due to the impacts on the coastal zone which normally receive minimal erosion impacts from storms e.g. Currarong in Jervis bay as seen in Figure 6 where steep erosional scarps occurred.

Figure 6 Erosional Scarp at Currarong in Jervis Bay NSW (Taken by Author)

2.6 New South Wales Coastal Management and Governance:

Within the NSW coastal setting, management and protection is undertaken through a division of responsibilities between the State and Local governments. State legislation provides the platform for management of the coastal environment, as seen through the *Coastal Protection Act* (1979) and *NSW Coastal Policy* (1997). Within the legislation or NSW Coastal Policy, it is stated that local councils are the primary body in which development and planning in the coastal zone is considered and reviewed; with local councils recommended to address the application of the policy through the recommended management plans within the Local Government Act (1993) (NSW-Government 1997). However, advancements in the coastal setting have occurred over time as evident through new policy reforms to occur including a NSW Coastal Management Act (2016) in draft phases to replace the current *Coastal Protection Act* (OEH 2016).

2.6.2 Coastal Zone Management Plan (CZMP)

In accordance with the Coastal Protection Act 1979, councils across the NSW coastline may a develop Coastal Zone Management Plan (CZMP) (Figure 7) in order to address a range of issues affecting the coastal environment and the associated stakeholders. CZMPs are principally used to outline and describe programs undertaken by a combination of councils, companies from the private sector and other public authorities to address issues including managing risks to the general public safety and built assets, pressures on coastal environments and the community use and engagement with areas in the coastal zone (NSW-Government 2013). Furthermore, CZMPs are normally required to support the objectives and goals stated within the *NSW Coastal Policy 1997* to be an effective guide for the coastal management community.

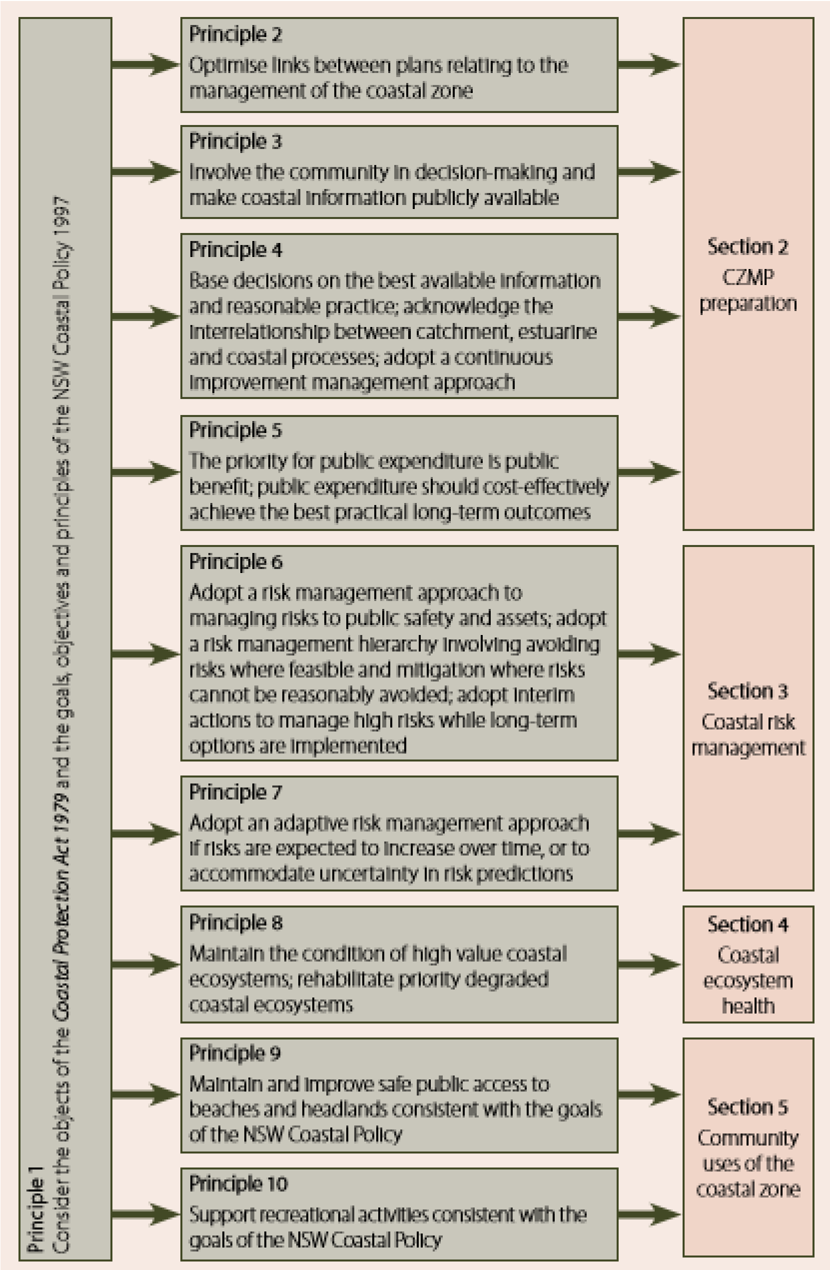


Figure 7 Principles to be considered during the CZMP preparation process (NSW-Government 2013)

3. REGIONAL SETTING

3.1 South Coast and Illawarra Coastal Environment

This study encompasses several regions and LGAs all located south of Sydney, including the Illawarra, Shoalhaven and Eurobodalla regions in NSW (Australia). The regions are similar in terms of climatic influences, geologic history and wave, tidal and wind conditions.

3.1.1 Climate

The Illawarra and south coast experience similar warm, temperate and humid climates which is consistent along the NSW coastline. The regions are characterised by warm, humid summers and relatively mild winters with rainfall relatively evenly distributed over the year with a yearly average 1187mm((BOM(b) 2016);(BOM(c) 2016);(BOM(d) 2016)). The regions are encompassed by several local government areas (LGAs) relevant to this study including Wollongong, Shellharbour, Kiama, Shoalhaven and Eurobodalla.

Table 5. Summary table of meteorological conditions for the south coast and Illawarra regions

Study Location	Closest Weather Station	Summer Temp Range ^{o}C	Winter Temp range ^{o}C	Mean High Temperature ^{o}C	Mean Low Temperature ^{o}C	Annual Rainfall mm/yr
Woonona	Bellambi	19-25	10-17	21.3	14.7	1113.9
Perkins	Albion Park	17-27	6-18	22.5	22.5	922.7
Warilla	Albion Park	17-27	6-18	15.1	15.1	922.7
Werri Beach	Kiama	19-25	10-17	21.3	14.6	1187
Currarong	Nowra RAN station	16-27	7-16	22.3	11.5	901.5
Moruya (Bengello and Pedro)	Moruya Airport	16-25	4-17	21.4	10.1	794.6

3.1.2 Coastal Geomorphology

The Illawarra region lies within the Sydney Basin, a tectonically stable region which also encompasses the far northern reaches of the Eurobodalla region (Woodroffe 2003). Many of the beaches within the Illawarra region are sandy barrier beaches consisting of Quarternary sediment with predominant sediments present being quartz rich sands.

3.1.3 Tides, currents and Wind-Wave Climate

The Illawarra, Shoalhaven and Eurobodalla regions are dominated by south to southeast swell (Short 2007). This prevailing swell direction influences sediment transport by causing a net northerly sediment transport direction providing sediment accretion at northern ends of beaches across these regions (Short and Woodroffe 2009). Headlands however prevent continuous transport due to wave refraction, thus producing compartments across these coastal settings, with the headlands also decreasing wave energy across these environments resulting in embayed beaches being commonly distributed across the regions (Short 2010).

These regions receive wave direction from other means including sea breezes, tropical cyclones, high pressure systems and east coast lows.

3.1.4 Vegetation Present on Dune Systems

NSW beach-dune systems experience a range of coastal vegetation of both natural and exotic species. Several of the main species are displayed below. Appendix 2 outlines species present.

Acacia Longifolia subsp. Sophorae: This species is commonly known as Coastal wattle. It is a native shrub and ranges in height from 0.5-5m.

Spinifex Sericeus. This species a pioneer vegetation species commonly known as spinifex.

Lomandra Longifola. This species is a native shrub and is commonly known as Coastal teatree. It ranges in height from 1.5m to 6m.

Cakile maritima. This introduced shrub is commonly known as European sea rocket. It can range in size from 0.5m to 1m.

3.2 Illawarra and South Coast Beach-dune characteristics

The Illawarra region and south coast region comprise several LGAs as stated previously. Within the Illawarra there are three Local Government areas which include; the Wollongong LGA consisting of 23 beaches beginning in the north at Stanwell Park extending to Perkins beach; Shellharbour LGA comprised of 5 beaches extending south from Warilla beach to the mouth of the Minnamurra River; Kiama LGA consisting of 13 beaches extending south from the mouth of the Minnamurra River to Seven mile beach. Moreover, the Shoalhaven LGA consists of 13 beaches extending South from the Shoalhaven Heads to Kiola and the Eurobodalla region encompasses 83 beaches extending south from Durras Lake to the mouth of Wallaga Lake. The study beaches included in this study are summarised within table 2.

Table 6 Study beaches examined within this study with rationale behind selection.

Beach Name	Storm Lidar 15/06/2016 (Y/N)	Recovery LiDAR 29/11/2016	Surveying completed (Y/N)	Vegetation Assessed (Y/N)	Local Government Area	Natural, Semi Natural or Unnatural
Woonona	Y	N	Y	Y	Wollongong	Unnatural
Perkins	N	N	Y	Y	Wollongong	Semi-natural
Warilla	Y	Y	Y	Y	Shellharbour	Unnatural
Werri	N	Y	Y	Y	Kiama	Unnatural
Currarong	Y	Y	Y	Y	Shoalhaven	Unnatural
Pedro	Y	Y	Y	Y	Eurobodalla	Natural
Bengello	N	Y	Y	Y	Eurobodalla	Semi-Natural

3.2.1 Woonona beach

Woonona beach is 1.1km in length with waves averaging 1-1.5m with usually an attached bar cut by rips every 200m present (Short 2007). It is a contentious beach with local stakeholders due to a variety of issues including amenity for beach users and the SLSC, as well as a need to be properly maintained by the council to mitigate issues such as invasive species, erosion and long term erosion. In recent years, the northern section of the beach has received the most human influence with clearing back of foredune vegetation blocking line of sight of life guards to the ocean. With most issues surrounding vegetation arising from balancing beach amenity and line of sight issues with the surf lifesaving club (Wollongong City Council, 2015), vegetation works need to resolve long term issues arising from the infestation of national weeds of significance including bitou bush and asparagus fern. Other human influences at the site include beach paths, the coastal walking track and infrastructure such as housing, roads and the surf lifesaving club.

The beach restoration program of the 1970s and 1980s saw dune reshaping, fencing and vegetation planting. In response to scarping from the June 6th storm event, scarping was slumped by machinery to mitigate safety risks.

3.2.2 Perkins Beach

Perkins beach at Port Kembla has a length of 7.2km and has the Port Kembla SLSC at the northern end and Windang SLSC in the south with most of the beach backed by stabilised dune (no landward migration)(Short 2007). The dunes in the 1930's and 1940's were of significance to the area due to the landward progradation of dunes by hundreds of metres threatening houses(Short 2007). Dune revegetation works done between the SLSC and Lake Illawarra in the South has resulted in stabilisation of dunes and combating invasive species (Wollongong City Council, 2010). The beach is easterly facing and has persistent rips every 200-300m which dominate the beach. Aside from stabilisation and revegetation works, the crown land and nearby areas surrounding the dune system experience little human influence aside from access tracks to the beach for recreation.

3.2.3 Warilla beach

Warilla beach is a curving easterly facing beach which is approximately 2km in length. The northern end of the beach is backed by an entrance training wall followed in a southerly direction by natural dunes with a predominance of natural vegetation species stabilising the dunes near the Warilla SLSC with a high rock sea wall for housing protection terminating at a groyne near the creek at Barrack Point. The southern section of the beach saw houses nearly washed away after severe storm conditions in the mid 1970's hence the sea wall was constructed to mitigate erosional impacts on infrastructure and homes. The beach receives waves averaging 1.4m with fine sediments producing a double bar system with the inner bar cut by 6-8 rips with intensity and length decreasing toward the northern and southern ends of the beach (Short 2007). Aside from the groyne and reshaping of the southern section through the rock wall, the beach has human influences through vegetation clearing for the surf lifesaving club and housing and infrastructure such as pathways and car parks.

Dune works as part of the 1970's beach restoration saw dunes raised, recontoured and revegetated to minimise wash over from storm.

3.2.4 Werri Beach

Werri beach located within the Kiama LGA is a popular holiday destination and thus has had considerable management undertaken to effectively meet the needs of all stakeholders involved including residents, recreational users and managers (Short 2007). This aspect of human modification is exemplified by the beach dune system being stripped of vegetation completely through bulldozing and reshaped with revegetation works (Kesby and Druett 1992).

Werri beach is classed as an embayed beach, whilst having a fixed sediment supply and considered to have a southern eroding section. Werri beach is accessible through footpaths from the main road with the hind dunes backed by urban development features including housing, surf clubs, car parks and a caravan park.

Werri beach has an easterly aspect with a rough system length of 1.9km; a 200m barrier width and a drained coastal lagoon at the northern end of the system which enters the ocean with Ooaree Creek (Short 2007). The system is exposed to wave conditions with an average height of 1.6m in the northern end and 1.4m in the southern end, with the beach maintaining one bar parallel to the shore and several strong rips along the lengths particularly at the northern headland and southern rocks (Short 2007). The beach has been influenced upon human activities since 1899 with the introduction of a recreational ground behind the beach, followed by the introduction of a surf club at the southern end of the beach in 1914 with subsequent upgrades performed in 1953 and the development of housing and caravan park and associated infrastructure to sustain this development (Short 2007).

Due to the domination of a Bitou bush plantation degrading the beach length, vegetation reassessment occurred during the 1990's. This was evident through the breakdown of the form and stability of dunes via blowouts where the Bitou had been degraded by salt and wind action thus facilitating the landward deposition of sand onto homes and roads (Kesby and Druett 1992). Vegetation management employed to remediate this issue involved a trial of Bitou bush removal, where the weed was pushed into large trenches dug into the foredune, with the removed sand used to cover the weed and reshape and mould dunes to appropriate guidelines outlined in the Dune Management manual (Kesby and Druett 1992). Subsequent re-vegetation of the moulded dune occurred with native seeds planted of Marram grasses, *Spinifex*, and *Acacia longifolia var. sophorae* modelled from surrounding beach vegetation locations with dune management continued by local dune care groups to maintain the natives and remove lingering Bitou bush (Kesby and Druett 1992). Vegetation and the dunes at Werri beach were cleared at the southern end of the beach for recreational purposes, however during the 1974 storm event, the southern end of the beach was removed entirely with the storm cut reaching the main road in front of the surf club (Doyle 2013). This therefore highlights the importance of dunes and vegetation to act as a protective barrier to storm impacts and the implications of human influence on vegetation through revegetation programs such as Bitou bush removal likely complicating beach dune responses (Doyle and Woodroffe 2015).

Figure 8. Werri Beach (North facing), 2016 (taken by author); Werri beach Bitou removal and placement into trench (Provided by Kiama municipal Council, image sourced from Doyle 2013)

3.2.5 Currarong:

Currarong beach is joined with Warrain beach in the north in a continuous 7km arc, which is densely vegetated with Currarong Road situated behind the vegetation(Short 2007). The foredune is approximately 10m high with the road behind backing the beach to southern Currarong where housing behind the foredune is present for the last 1km of the beach between Plutus and Currarong creeks(Short 2007). The area is managed consistently to reduce dangerous high scarping and undercutting of walkways by the Shoalhaven City Council, with sand nourishment programs, scarp slumping and maintenance of structures such as artificial walkways (Shoalhaven City Council, 2007). Human influence on the site is primarily seen through a variety of recreational uses of the beach, in conjunction with the Currarong Creek used to launch and anchor small vessels (Short 2007). The council has recommended several beach-dune system management options including dredging the creek, implementation of groynes, in situ textile bag support for undermined pathway structures (Shoalhaven City Council, 2007) to address a range of issues including long term recession and erosion of the beach. Post the June 6th storm, severe scarping of the dunes has resulted in the council addressing safety issues by influencing the dunes through beach scraping and sand nourishment with sand dredged from the creek and placed at the toe of the dune. The beach receives average wave heights of 1.4m.

3.2.6 Bengello Beach (Moruya):

Bengello beach with Broulee SLSC at the northern end and a training wall for the Moruya River is one of the longest beaches on the South Coast at a length of 6km (Short 2007). The beach is backed by a series of densely vegetated foredune ridges that formed during shoreline progradation 6000-3000 years ago(Short 2007). The northern end of the beach where the surf club is situated has been cleared of some vegetation to avoid amenity impacts on the surf club for safety reasons, with other human influences evident at the southern end where the Moruya airport is present, with clearing have occurred near the boundary fencing of the airport for visibility reasons. The beach receives waves of 1.6m at the centre of the beach, with the northern end protected from North-east swell, and the southern end receiving waves of 1m. The inner bar spanning the beach is cut by rips every 300m. Bengello beach has been studied for many decades (McLean, Shen et al. 2010) investigating beach recovery, swell and wave conditions.

3.2.7 Pedro Beach (Moruya):

The northern end of Pedro beach contains the Moruya Heads SLSC, with a caravan park located just to the south, followed by National park extending south(Short 2007). Similarly to Bengello beach, the well vegetated low foredune is back by 100m of low foredune ridges backing the entire beach, with an access road running the length of the beach. Moreover, there is a proliferation of natural vegetation with minimal human influence in the national park area. The beach is 2.4km in length with waves average 1.5m in the north decreasing in a southerly direction and the beach is accompanied usually by a bar cut by several rips in the north and grading to a continuous low tide terrace in the south (Short 2007).

4. METHODS

Several approaches were used to examine the impact of the June 6th storm in 2016 upon the study sites in the South coast region and the subsequent recovery period. These approaches were used to examine the physical characteristics, change and behaviour of the beach and dune systems. Each method aimed to capture coastal process data associated with post-storm recovery for use in management of affected and at risk coastal locations. Each method employed was aimed at determining whether scarp height influences recovery of scarping through slumping, a primary aim of this study. The secondary objective to examine if there is a trend between vegetation species present on the scarp and scarp height was examined also using these methods. The main methods undertaken within the scope of this project to assess beach-dune morphology and vegetation included:

A) Photographic assessment
B) LiDAR analysis
C) Real Time Kinematic (RTK) GPS surveying and Vegetation surveys

The shape and height of scarping was first examined using photographic

The primary objective of determining the relationship between scarp height and recovery time (i.e. do higher scarps take longer to recover) is assessed through visual analysis of both photographic evidence and LiDAR derived profiles, as well as GPS surveys, which visualise and records how the scarp changes through time.

Through the examination of the dominant species of vegetation, height of scarping, trends between rate of recovery and vegetation type can be determined and assessed between and within beach systems to determine the secondary objective of this study. This can allow for more informed future coastal management decisions regarding vegetation management for dune systems and larger scale coastal management.

4.1 Photographic assessment

Photographic assessment of beaches was undertaken to assess visually the extent of storm damage through erosional scarps and other impacts including walkway undercutting and dune fencing. Photographic evidence of storm impact upon beach-dune systems considered in this study was used to visually assess how the beach was affected in different areas through examination of scarp height and shape immediately post storm and during recovery. Photographic evidence is beneficial in cataloguing impacts of storms of varying magnitudes and to collate information about beaches at a certain point in time during processes such as erosion and recovery. Visual interpretation of images provided by the OEH (Aimee Beardsmore and Daniel Weicek) allowed for trends regarding scarp height through time to be identified.

4.2 LiDAR

Light detection and ranging (LiDAR) data can be used for morphological examinations such as providing 3D formations of beach-dune systems including the height of the scarping of beaches post major storm events. LiDAR data is useful in developing TIN (Triangulated Irregular Network) digital elevation models (DEM), which are spatially displayed in ArcMap as a data layer. LiDAR data used in this study was Airborne Laser Scanning data, which captured terrestrial areas of interest; predominantly the berm and dune-systems for selected beaches on the 15/06/2016. The immediate post data was captured by the University of New South Wales school of aviation for the NSW Office of Environment and Heritage with post storm data capture dependent on the population and management needs of the beaches in question. Elevation data is collected through the measurement of laser pulses which are aimed at the ground and rebound back to the scanner (Saye, Van der Wal et al. 2005). The LiDAR data taken in November was donated by Jason Middleton and Peter Mumford from the University of New South Wales for this study.

The process of creating TIN maps occurs through the conversion of raw LAS files to elevation points in ArcMap through using the “las to multipoint tool”; this output is clipped to an area of interest polygon (i.e. the foredune), with the final step involving the “create TIN” tool to generate the TIN DEM for examination for both immediate post-storm impact and recovery LiDAR sets (Figure 9). The TIN was visualised as a three-dimensional representation of beach-dune systems in ESRI’s ArcScene to allow for visual examination of the presence of storm cut (Figure 10).

The TIN DEM’s were subsequently examined using the “point profiler tool” on the 3D analyst tool bar. This allowed for the production of derived profiles allowing for alongshore variation to be examined. This further examination provided visualisation of scarp height and shape during the recovery process through time for the June and November LiDAR sets.

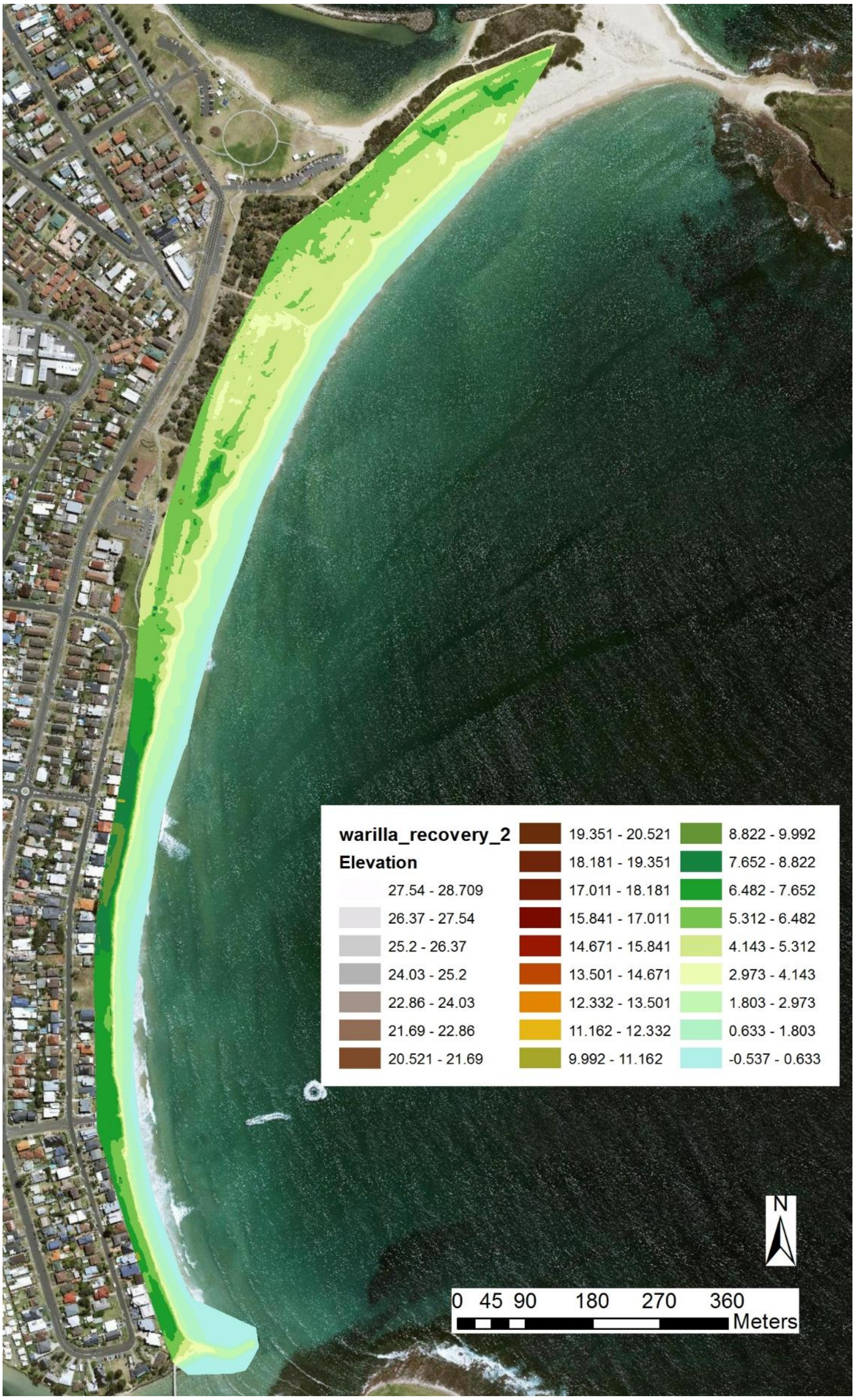


Figure 9. LiDAR derived DEM of Warilla Beach during recovery (LiDAR provided by UNSW and base imagery source LPI Imagery layer

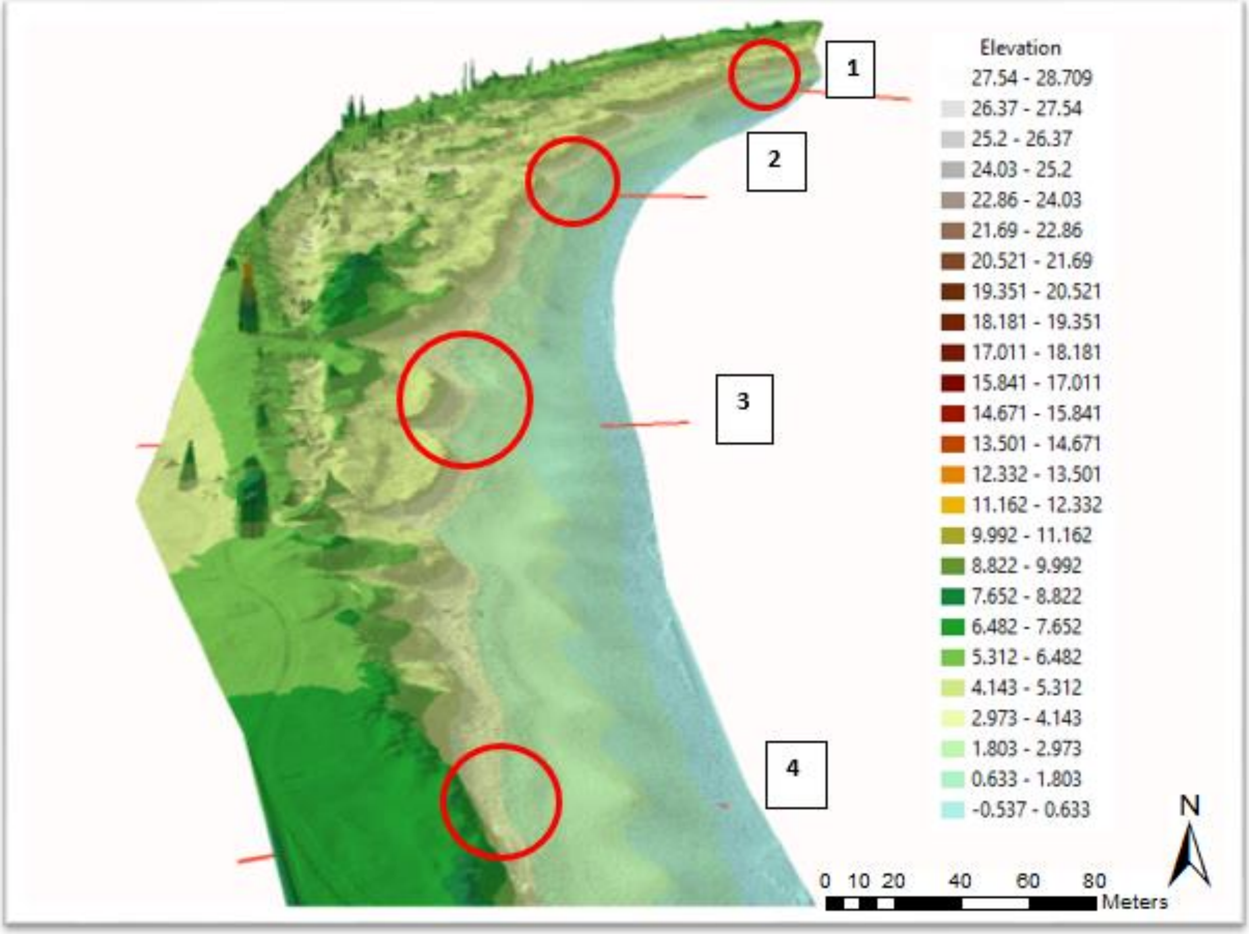


Figure 10. Three Dimensional view of Warilla beach looking North derived from LiDAR DEM of data captured in November. Vertical exaggeration of 3. Red circles denote storm impact of interest at derived profile sites during recovery

4.3 RTK GPS Surveying and Vegetation Assessment

A Trimble Real Time Kinematic (RTK) rover was used to create profiles of the beach-dune systems of the beaches of the Illawarra and South coast region examined in this study. The RTK enables the capture of data through connection to the closest GPS base station (the CORSnet network) via a mobile internet connection on the 3G or 4G network. This allows for the user to create topographic profiles through capturing a series of GPS points in the areas of interest in beach-dune systems. The CORSnet network in NSW is a network of permanent satellite navigation tracking stations to enable equipment and machinery to determine positioning in an accurate manner (vertical accuracy 0.03m (Harley, Turner et al. 2011)) (NSW-Government 2016) CORSnet is used to increase resolution of points taken by the RTK (NSW-Government 2016). For the purpose of this study, the coordinate system used on the RTK was GDA zone 56, which is the map grid of Australia with height geoid model Ausgeoid 2009 used. By employing these coordinate systems, this can provide accurately positioned points and associated height recordings of the dune scarp and dune-beach profiles, allowing for more accurate mapping spatially in ArcGIS. Surveying was undertaken by Tom Doyle from the immediate storm impact until September when the author began surveying.

The surveys conducted were perpendicular to the shoreline to capture the height of the foredune and scarping of the remainder of the incipient foredune to provide the beach and dune profile. Surveying was undertaken monthly after the June 6 storm for the profiles at Woonona, Warilla, Perkins and Werri Beaches to provide a temporal scale for beach recovery after the impact of the June 6 storm. Surveying was undertaken at each profile beginning at the most landward extent of the dune systems (where satellite connection was continuously available); which included behind hind dunes, foredunes or at manmade structures such as fences depending on what was present at each study site. The use of fence posts, signs and concrete paths were integral in use as continuous points to allow a profiles to be assessed through different time therefore achieving a comparison of profiles, by having a consistent reference point. The surveys at each site across the Illawarra and south coast regions had a minimum of two profiles to a maximum of 5 profiles at each dune-beach system. The profiles were obtained by selecting the RTK to take points in a manual selection at intervals of approximately 0.5m to obtain detailed topographic points.
The surveys were then displayed in excel to highlight how morphology has changed during the recovery period. Volumes calculated in excel using the RTK data were then used to show monthly volume change during the recovery phase. The surveys were then displayed in excel to highlight how morphology has changed during the recovery period. Volumes calculated in excel using the RTK data were then used to show monthly volume change during the recovery phase. Volumes were calculated to a set AHD with volume calculated beneath the profile to get a volume for the profiles.

4.3.1 Vegetation Assessment

Vegetation assessment of the beach-dune systems was undertaken with the RTK surveying of the dune scarp and profiles within several beach systems. This was undertaken to determine trends between dominant species of vegetation present along the scarping and the influence of this vegetation upon scarp height and the volume changes of the systems during the immediate storm impact and subsequent recovery period.

Dominant species and species extent was noted along the scarping with photographs taken for species identification and to photographically show the species extent at a certain point in time. Native species and introduced species were assessed within Natural, semi-natural and unnatural beach systems at profiles to determine trends in erosion and accretion. Dominant species were noted along profiles to further discern the influence of vegetation present upon volumes for the profile during accretion and erosion phases within beach systems. By comparing beach-dune systems and profiles within these systems, the influence of vegetation type on recovery and storm impact could be more effectively examined to ensure more applicable management implications for trends highlighted for the entirety of the NSW coast.

5. RESULTS

The analysis of LiDAR data, GPS surveys and vegetation surveys along the south coast of NSW highlighted the highly dynamic nature of the beaches considered in this study. This dynamic behaviour is especially apparent during the highly erosive storm events that impacted beaches on June 6th 2017 and subsequent period of recovery. This period was examined to investigate the primary aim of determining if a trend exists between scarp height and the recovery time of the scarp post large storm events. This primary aim was of relevance as a result of the work of Hesp (1988) who presented the hypothesis that higher dune scarps take longer to recover compared to smaller dune scarps. A secondary aim of determining if a relationship exists between vegetation species present along the scarp and scarp height during the recovery process was also investigated. This study of short term beach change (post the June 6th event) was conducted through beach profiling, which has shown fluctuations in dune and sub-aerial beach volume during the recovery period. A recovery period of 5 months was chosen during surveying, with recovery LiDAR data also obtained 5 months after the event. During this period, differences in the coastal vegetation between beach compartments and within beach systems during surveying. It must also be noted LiDAR was not available across all study beaches during the immediate post storm period and the recovery period capture. Due to this, the results will focus on beaches where both sets of LiDAR were available.

This chapter begins by describing the immediate storm impact of the June 6th event through examination of immediate post storm photographs and will continue to asses data derived through a liDAR derived TIN surface comparison. This is followed by an assessment of the main vegetation present along each coastal compartment. This is followed by examining scarp elevation derived from LiDAR analysis produced with ESRI's Arc GIS. The recovery period was examined firstly by examining visualised scarp height changes, followed by examining volume changes for individual profiles within beaches determined through RTK GPS surveying.

5.1 June 6th Storm Impact on south coast beaches photograph analysis

The impact of the June 6th storm event will be examined through the examining of photographs taken immediately after the event by Aimee Beardsmore, Daniel Weicek (OEH) and Ray Massie (Shoalhaven City Council). Photographs are an essential record of storm impacts as they present visual evidence to allow for comparison between beach-dune systems, as well as between storm events that occur. Comparing these photographs with photographs taken several month later also provides visual evidence of the recovery of the beach. Warilla beach, Currarong beach and Bengello beach will form case studies to examine the storm impact.

5.1.1 Warilla Beach

Warilla Beach was impacted upon by the storm through erosion of the beach-dune system causing undercutting of walkways, exposure of the rock wall and through dune scarping. Daniel Weicek from the OEH photographed the beach on the 7th of June 2016 (Figures 11-13), showing the immediate impact upon the beach allowing for visual inspection of how the beach was altered from this event. Due to the north-east aspect of the storm, the southern ends of beaches across NSW were impacted to a greater degree than the centre and most importantly the northern end of the beaches. Figure 11 shows the northern end of the beach with fewer erosional impacts evident, such as large scarp height.

Figure 11. Warilla beach looking north from the centre of the beach on the 7th of Dune. Note the erosional scarp present which decreases in height towards the northern end. (Photo by Daniel Weicek, OEH)

The highly erosional impact of the June 6th storm event was most evident at the southern end of the beach. Figure 12 a and b highlight the erosion of the beach and foredune with exposure of the rock wall protecting dwellings located at the southern end of the beach. The erosional impact is highlighted by the damage to fencing along the dune system which was eroded during the storm, as well undercutting of the walkway evident in 12 b. Scarping is present at the southern end of this beach as well, however the presence of the rock wall may have influence the height of the scarp in this case through preventing sand mobilisation.

Figure 12 Storm impact upon the southern end of Warilla beach. Note fence damage in a) and undercutting of walkway and rock wall exposure in B). (Source: Daniel Weicek OEH)

Figure 13 highlights the extent of the erosion along the southern end of the beach. A section of the rock wall can be seen in Figure 13 to have been possibly removed during the storm as in the image no rocks are evident, but the rock wall on either side of the area has a consistent wall protecting the dune and most importantly the housing located behind it.. This possible removal of the rock wall may indicate a possible failure of the wall due to a hotspot of erosion, however this is not examined within this study.

Figure 13 Southern section of Warilla beach on the 7th of June highlighting large wave conditions. Note the red box outlining a missing segment of the rock wall which may highlight a hotspot of erosion.

In summary, the beach at Warilla exhibited higher levels of erosion at the southern end of the beach which can be seen due to the presence of undercutting of walkways, exposure of the rock wall and damage to dune fencing. The southern section also display a higher erosional scarp that the central and northern sections of the beach which is consistent with the North-East aspect of the storm.

5.1.2 Currarong Beach

During the storm event Currarong beach was highly eroded with significant scarping, vegetation removal and infrastructure damage occurring. Ray Massie from the Shoalhaven City Council photographed the storm impact upon Currarong on June 6th, allowing for visual examination of the impacts. Currarong experienced high levels of erosion particularly at the southern end near the township. This was due to the north-east aspect of the storm waves impacting on the southern section of the beach the most, consistent for most beaches along NSW.

Figure 14Walkway undercutting and destruction at Currarong beach (6th of June 2016). Note vegetation removal and slumping upon the Scarp. (Source: Ray Massie, 2016)

The foredune experienced severe erosion of sand as seen through the high scarping and displacement of vegetation (Figure 14). Figure14 also highlights severe undercutting of walkways which is a significant safety issue for the general public.

Vegetation removal due to mobilisation of sand during wave erosion of the beach-dune system is highly evident in Figures 15 and 16 which shows large scarping and vegetation placement at the base of the dune during collapse after the event tracked further south and removal during the event itself. The highly erosive conditions uprooted established trees (Figure 16) which shows the power of the waves and a particular hot spot of erosion along the southern end of the beach.

Figure 15 Vegetation removal and scarping at Currarong on the 8th of June (Source: Aimee Beardsmore, 2016)

Figure 16 Note established trees have been removed during erosion and are placed along the berm on the 8th of June (Source: Aimee Beardsmore, 2016)

Infrastructure at the beach, namely tables and recreational seating where damaged by the wave conditions as seen below in Figure 17 where the picnic table has been tilted off balance due to the erosion of the ground where it previously stood. Also note the placement of vegetation from the foredune during the high wave conditions in this area.

Figure 17 Erosion at southern end of Currarong displacing recreational infrastructure (tables) and placement of eroded vegetation on June 6th. (Source: Ray Massie Shoalhaven Council, 2016)

5.1.3 Bengello Beach

Bengello beach near Moruya on the south coast also experienced scarping of the foredune. Photographs to examine the impact of the storm on Bengello beach were taken on the 28th of June by Daniel Weicek for the OEH. Whilst this was over 3 weeks after the event, scarping of the southern end of the beach was still evident. The presence of vegetation displacement from wave conditions was also still evident at this time (Figure 18 and 19). The northern end of the beach does not have photographical evidence available for examination, however due to the consistency of the storm impact across NSW beaches, erosional scarp height would most likely have been highest at the southern end.

Figure 18 Scarping along the southernmost section of Bengello Beach. (Daniel Weicek, OEH 2016)

Figure 19. Vegetation transported and placed during high wave conditions.(Source: Daniel Weicek, OEH 2016)

5.1.4 Summary

Through examining photographical evidence of the June 6th storm, several trends are apparent regarding the storm impact. For each case study beach considered here, the storm produced an erosional scarp which varied in height from the northern to southern ends of the beach. The storm eroded the southern ends of beaches to a greater extent and damaged coastal infrastructure through the damage to fencing on the dunes, as well as undercutting of walkways. Vegetation was also stripped from the dune system during the event and was found to be placed upon the berm of the beach in some cases, through wave conditions and erosional scarp instability.

5.2 June 6 Storm Recovery of Beaches on the South Coast

5.2.1 Warilla Beach:

Warilla beach was examined using liDAR DEM created within ESRI's ArcMap. Profiles were created along the beach to examine visually how recovery of the beach occurred between the LiDAR captures immediately after the storm and during the recovery period. This visual analysis provides the morphology of the beach at two certain points in time allowing the recovery of the beach to be examined, however this data capture does not provide insights into continual day-to-day and week-to-week variations which occur in the dynamic beach-dune environment. Figure 20 provides the spatial locations of the six profiles along the beach, overlaid upon the free access Land and Property information (LPI) imagery layer readily available online.

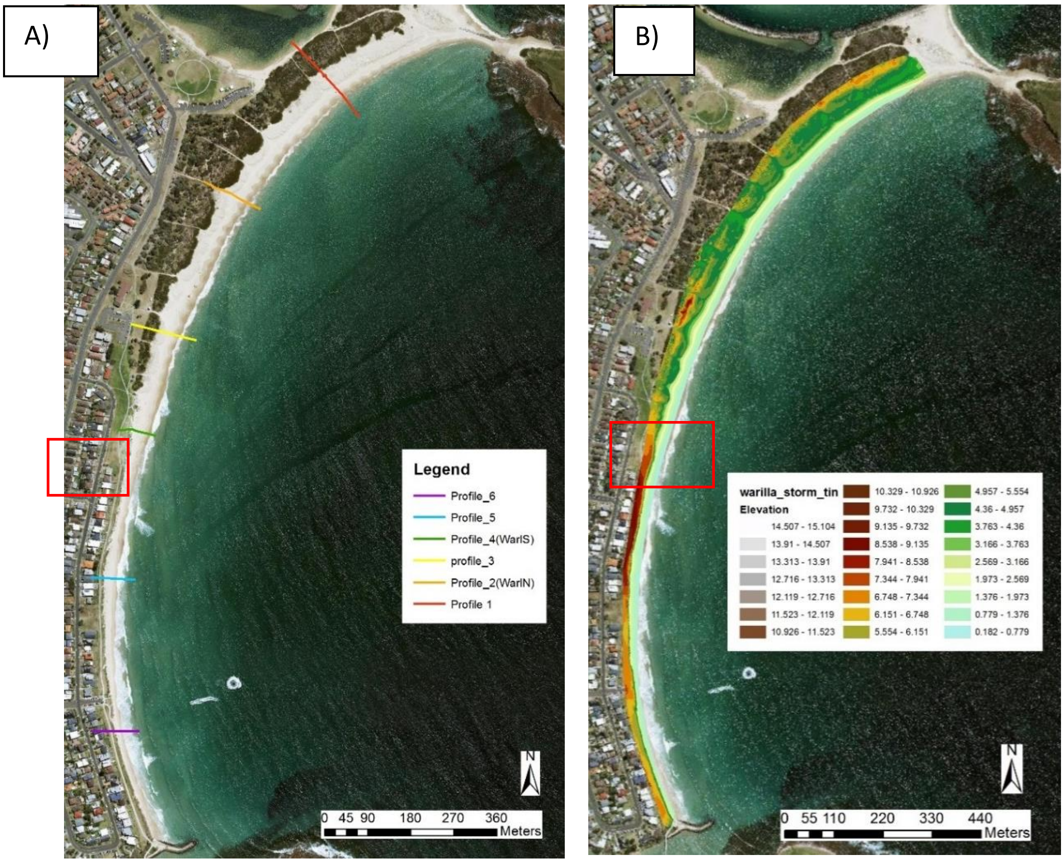


Figure 20 A) Profile Locations along Warilla Beach overlaid upon LPI Imagery Layer. Note the red box around profile 4 as 3D visualisation looking north occurs (see figure ( ); B) LiDAR derived DEM of Warilla Beach immediately post storm (LiDAR provided by OEH and base imagery source LPI Imagery layer {free to access})

The immediate post storm LiDAR was transformed into a TIN DEM to examine the extent of scarping upon the beach (Figure 20 B). However to effectively examine the scarping, the TIN was visualised in ESRI'S ArcScene to allow for three dimensional visual analysis of the scarping along the length of the beach. It must be noted that the immediate storm LiDAR did not receive significant pre-processing before being visualised in this study, with high variation in elevation occurring on the most landward extent of the DEM. This variation is consistent with vegetation being captured in the dataset as well as the ground points. Vertical exaggeration was used during the visualisation of the DEM in ArcScene to highlight changes in elevation in a more effective manner.

The immediate storm impact through scarping of the foredune showed some scarping at Warilla, but not a significant large vertical cut. Figure 21 shows Warilla beach looking north from the approximate middle of the beach at profile 4 (this is the profile surveyed using the RTK GPS- Warl S). From the northern most profile, the elevation of the beach does not indicated an obvious vertical scarp line, rather a small steep slope with elevation gradually increasing from the shoreline (0.182 m- light blue colour on DEM) to the foredune (4.3-4.9m).

Moving in a southerly direction, the elevation increases and reaches the highest point at profile 4, where a storm cut is most evident on this beach. The elevation of the foredune at this profile reaches approximately 7m according to visual analysis suggesting this area of the beach experienced higher levels of erosion.

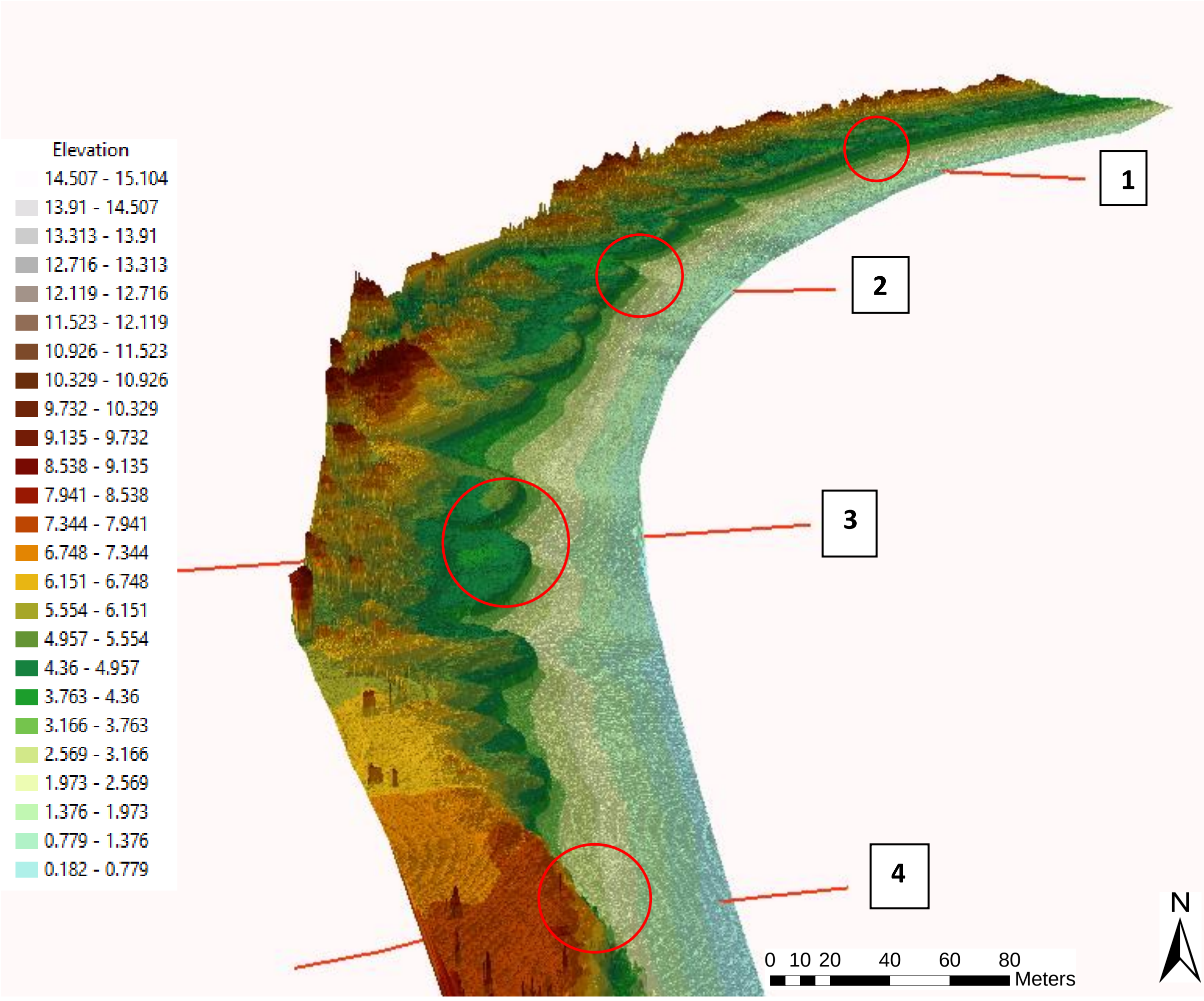


Figure 21Three Dimensional DEM of LiDAR data captured immediately post storm showing Warilla Beach facing north. Note the elevation displayed has a vertical exaggeration of 3 to highlight scarping. The red lines indicate profile locations for this beach with red

The southern section of the beach looking north is captured in Figure 22. The southern section of the beach was eroded more with higher scarping as a result of the storm tracking down the coast. This southern section had the rock wall exposed during the erosion period of the storm. Through the three dimensional analysis of the beach, visual evidence of scarp height increasing in a southerly direction (evident in immediate post storm photography).

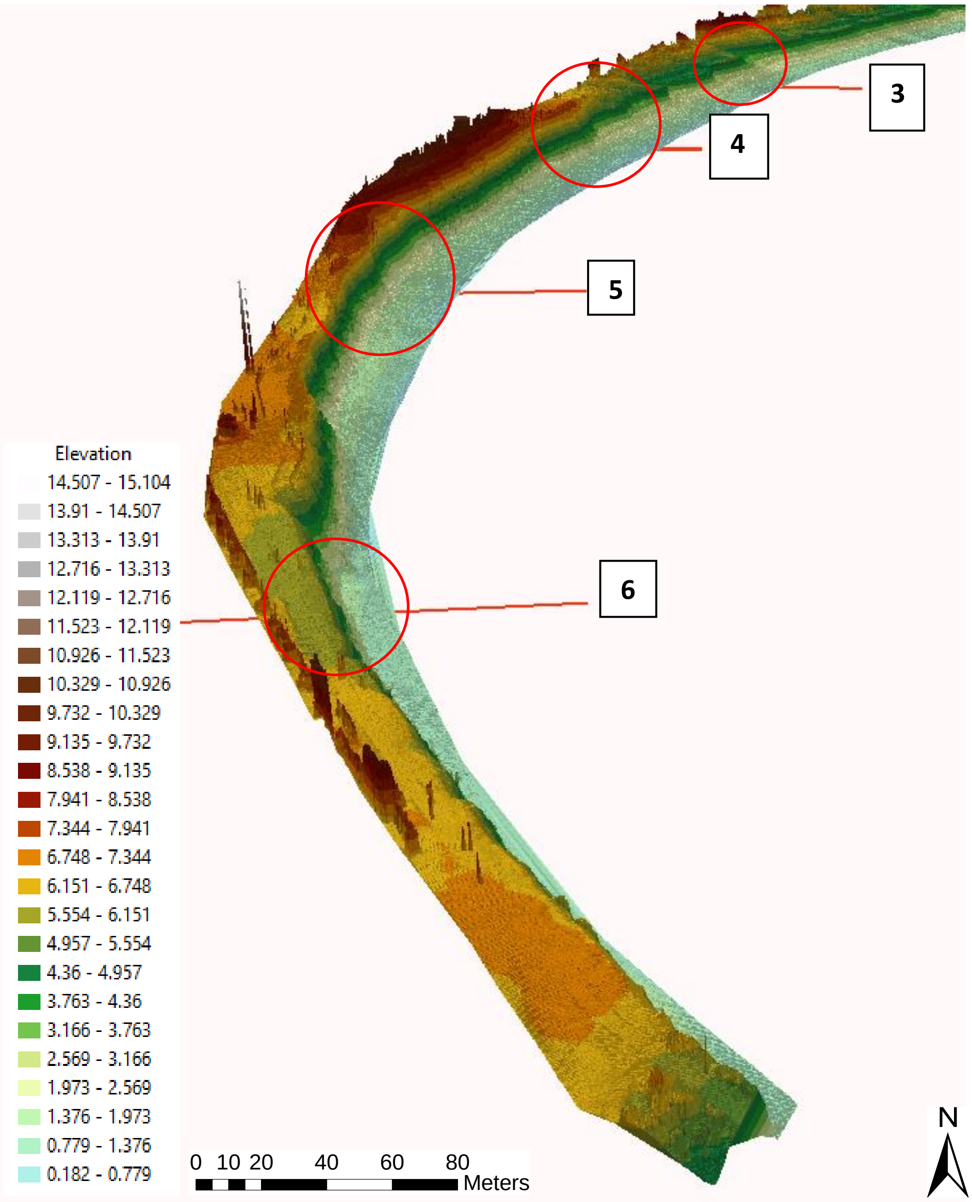


Figure 22. Three Dimensional DEM of LiDAR data captured immediately post storm showing Warilla Beach facing north. Note the elevation displayed has a vertical exaggeration of 3 to highlight scarping. The red lines indicate profile locations for this beach with red

LiDAR for the Recovery period taken by UNSW was created into a TIN DEM to examine the extent of scarping upon the beach during recovery to examine whether the scarp heights which were highest remain higher than lower scarp heights. This was done to examine the primary aim of examining whether higher scarps take longer to recover than lower scarps.(Figure 23A). The TIN was visualised in ESRI'S ArcScene to allow for three dimensional visual analysis of the scarping along the length of the beach during the recovery period. The recovery of scarping on the foredune showed some recovery (i.e. slumping) through this period. Figure 24 shows Warilla beach looking north from the approximate middle of the beach at profile 4 (this is the profile surveyed using the RTK GPS- Warl S).

Across the length of the beach, the general trend of scarp height decreasing is apparent, with the cut less vertical. This detail was examined using the point profiler tool

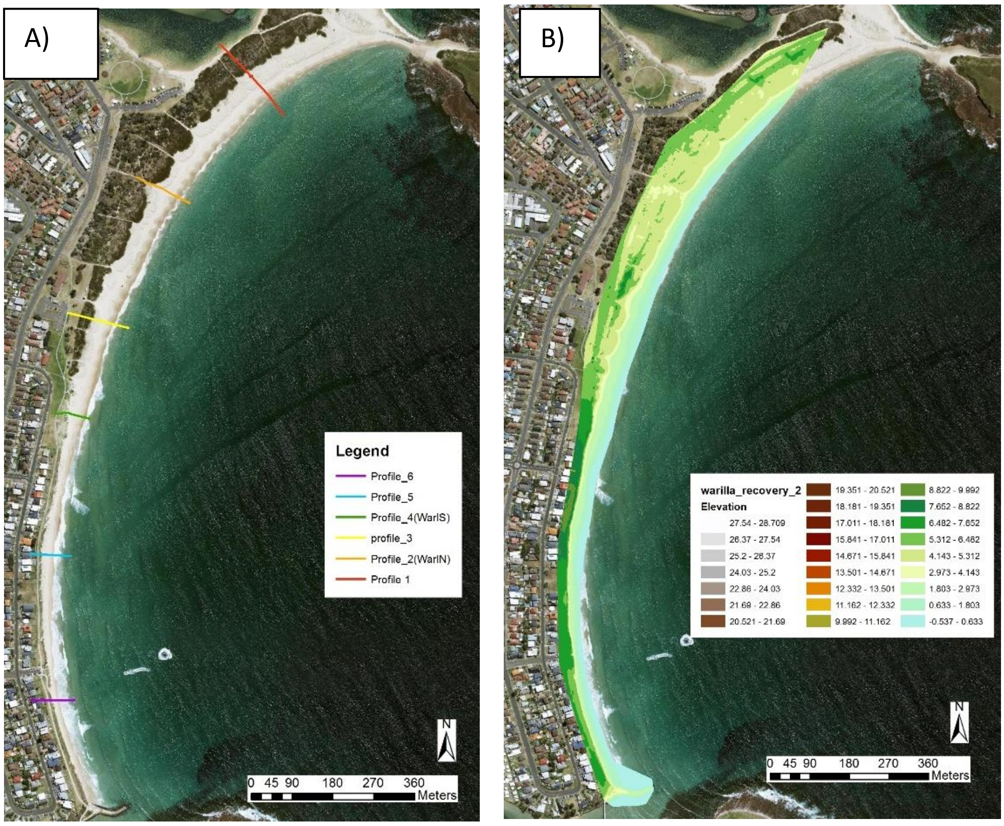


Figure 23 Three Dimensional DEM of LiDAR data captured immediately post storm showing Warilla Beach facing north. Note the elevation displayed has a vertical exaggeration of 3 to highlight scarping. The red lines indicate profile locations for this beach with red circles highlighting the scarp height at each profile

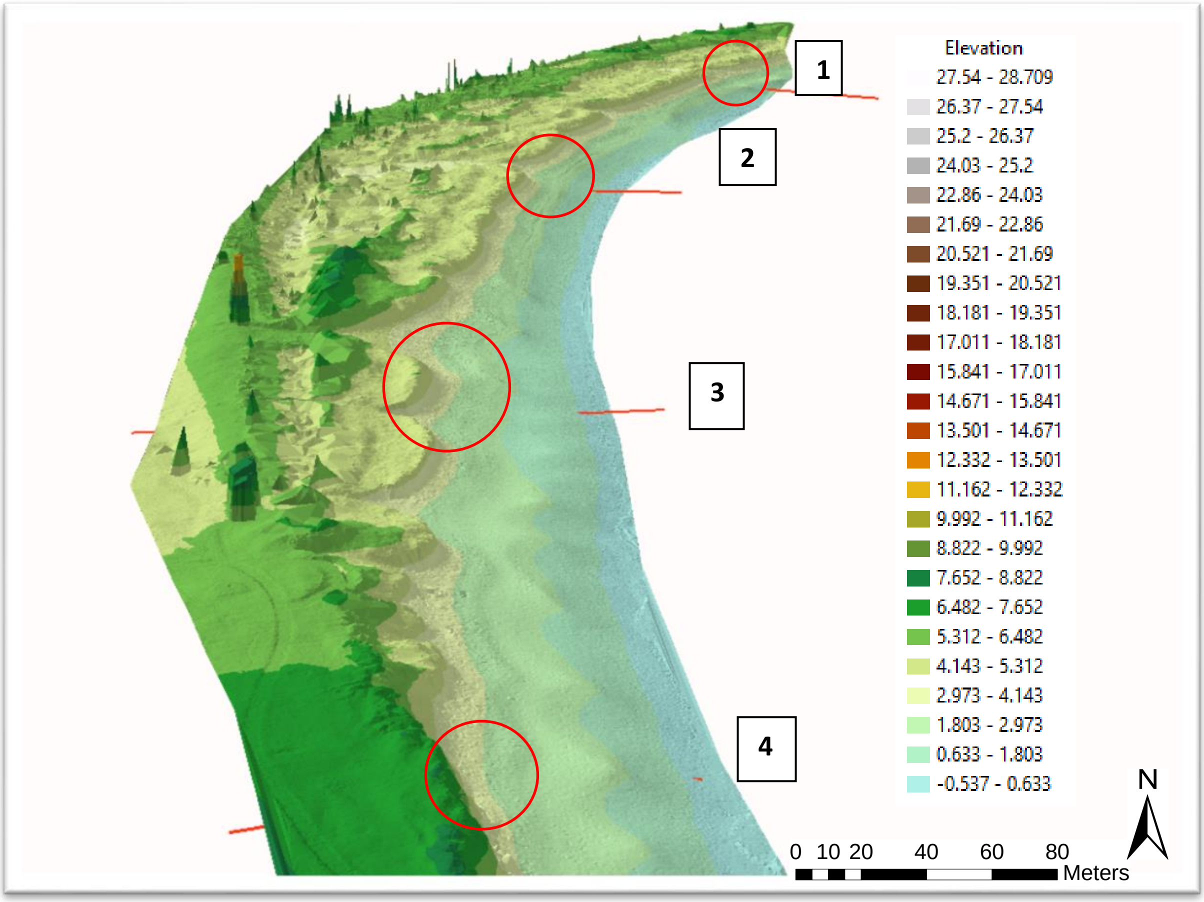


Figure 24. Three Dimensional view of Warilla beach looking North derived from LiDAR DEM of data captured in November. Vertical exaggeration of 3.

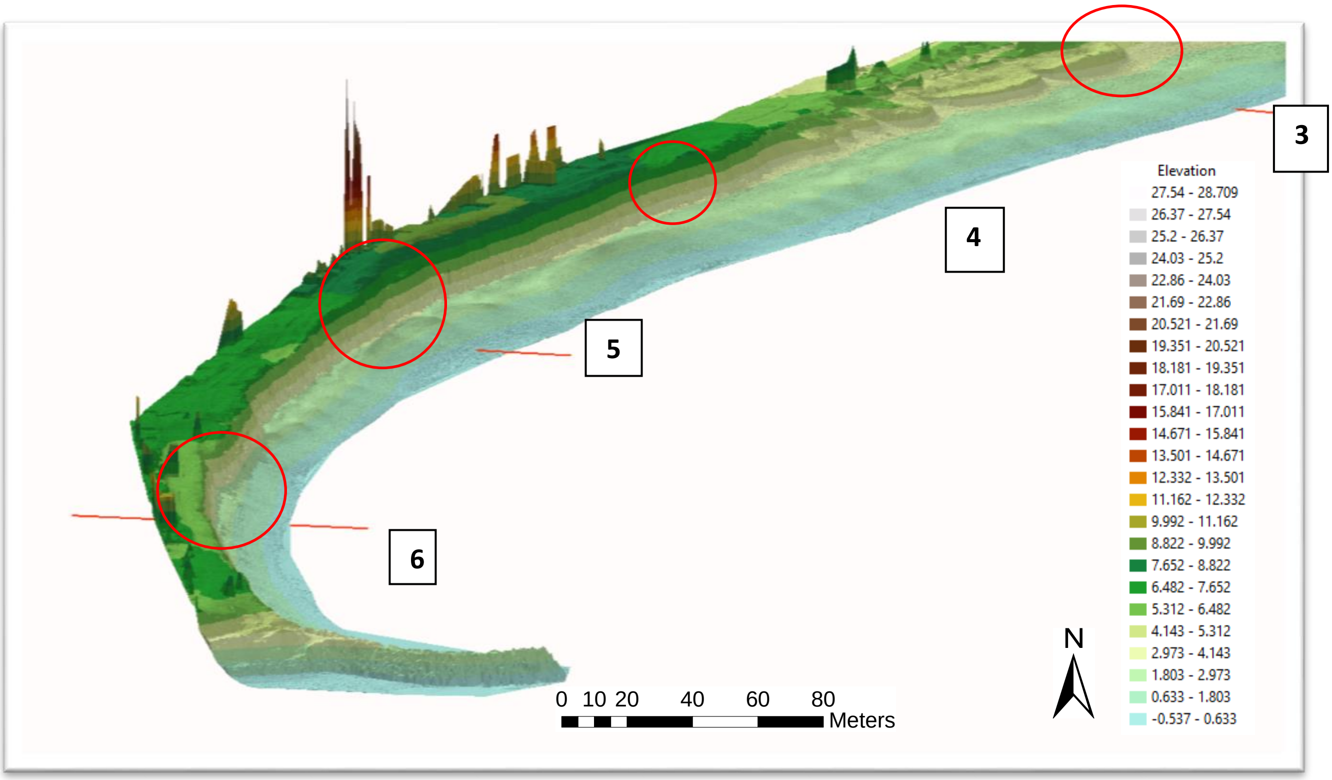


Figure 25. Three Dimensional DEM of LiDAR data captured immediately post storm showing Warilla Beach facing north. Note the elevation displayed has a vertical exaggeration of 3 to highlight scarping. The red lines indicate profile locations for this beach with red

To best examine scarp recovery between the LiDAR sets, the 'point profiler tool' was used to display the profile height beginning at the back of the foredune and finishing at the most-seaward section of the tin. This allowed for visual evidence of beach recovery which is not clear from examining the 3D DEM. The profiler tool was drawn over each TIN at the 6 profiles producing profiles for visual examination.

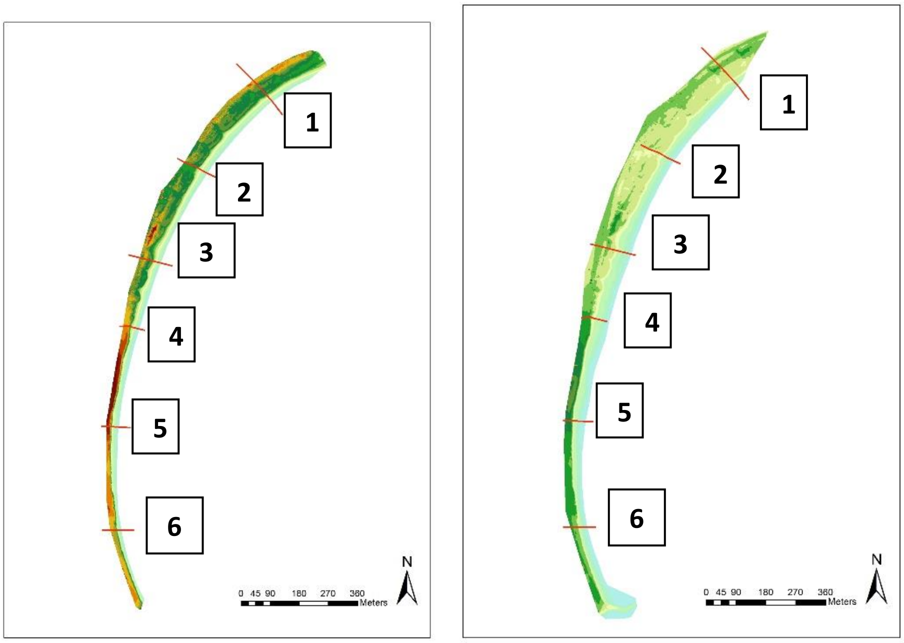
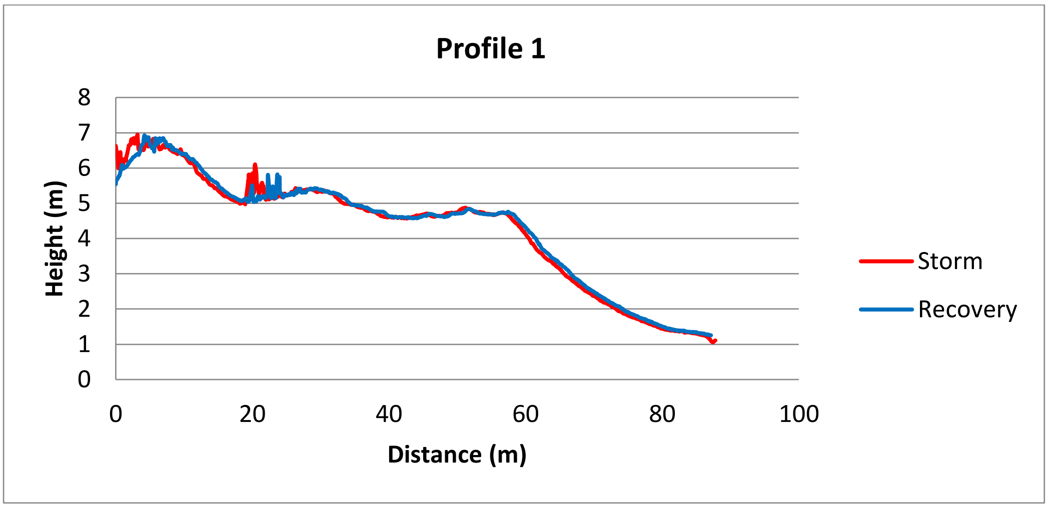
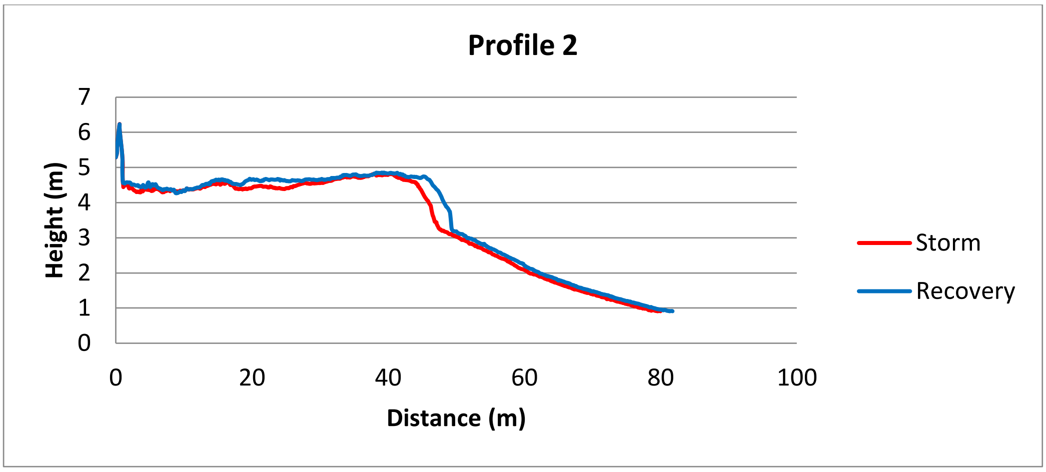


Figure 26 Storm and Recovery TIN DEMS with profile locations where point profiler tool was used to gain a visual display of the beach-dune systems during both times of data capture.





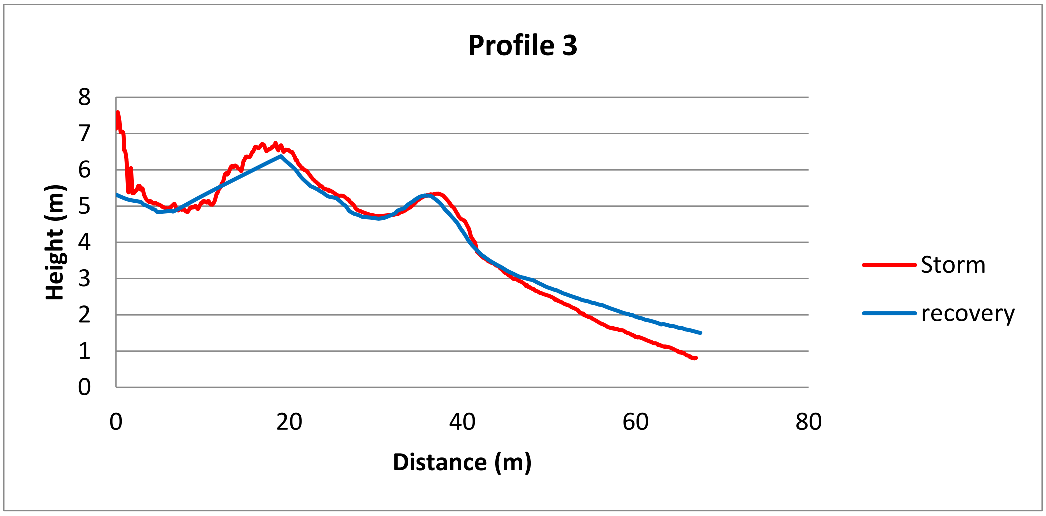
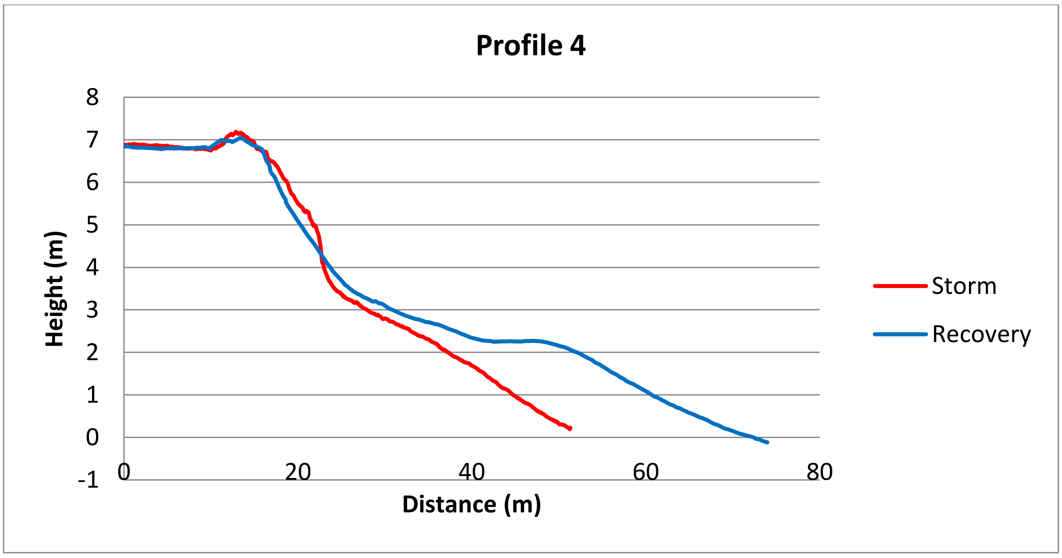
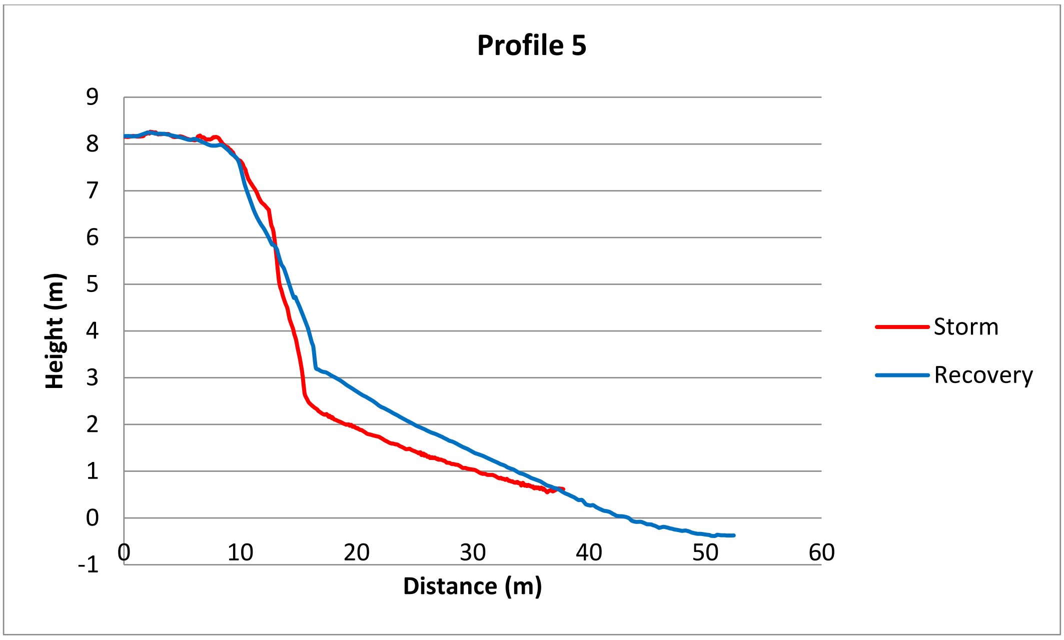


Figure 27 Profiles 1-3 Derived from both June and November LiDAR data (Data provided by OEH and UNSW)





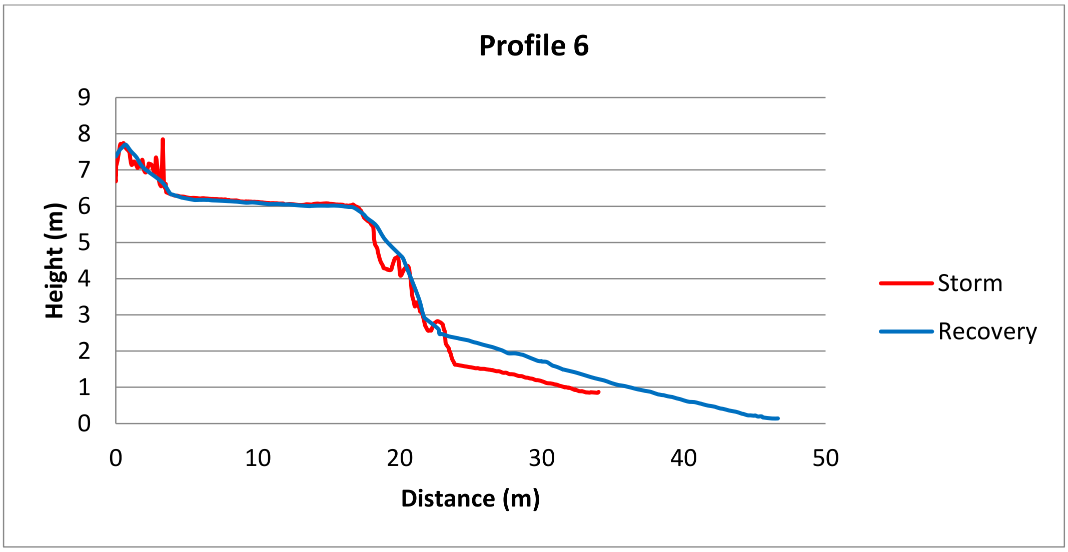


Figure 28 Profiles 4-6 derived from LiDAR from June and November LiDAR sets (Source: OEH and UNSW)

Profile One situated at the northern end of Warilla beach displays minimal storm impact due to be at the sheltered end of the beach from the North East direction of the storm. Some recovery did occur on the profile as seen through slight beach accretion however no discernible trend is evident for storm recovery due to the minimal nature of the impact on the northern end of the beach.

Profile two shows the dune scarp edge has built out in a seaward direction and lost some of the vertical cut which is consistent with scarping. The scarp height remained consistent around 4-4.5m in height however its shape is more ramp like in November rather than more vertical in June.

Profile 3 is located roughly halfway along the beach and had a small scarp of approximately 4.5m. The November profile exhibits a less vertical cut and more a slope. The beach also accreted during this period of recovery.

Profiles five and six display the largest scarping along the beach. These profiles both still retained the vertical cut for the longest period of time, with a vertical cut still evident in the recovering slumping process. These scarps were also the highest with scarping of 6-7m in height where rock wall exposure occurred.

5.2.1.1 RTK SURVEYING

RTK-GPS surveying was conducted alongside vegetation surveys to examine variation in morphology of several study beaches through time, with particular emphasis upon determining how scarp shape and height changed during the recovery process. RTK-GPS surveys were undertaken at Warilla beach, Woonona beach, Perkins beach and Werri beach. Warilla will be used as a case study. Warilla was surveyed at the northern and southern ends of the beach with 'warl m' corresponding to profile 2 and 'warl s' profile 4 (Figure 27 and 28). Tom Doyle (PHD candidate, UOW) surveyed these locations from the 10th of June monthly, until the 8th of September when the author took over surveying. 'Warilla m'

As evident in Figure 28, the monthly accretion of sand for the profile saw a building of the berm primarily. However, it is obvious in monthly surveys that the scarp lost most of its defining vertical cut by the end of surveying. This profile was found to be dominated primarily by *Spinifex sericeus*, with shrubs including *Acacia longifoloia* var *sophorae* and *Leptosperum Laevigatum* present behind scarping. Through detailing the vegetation present, the secondary aim of the study to examine the influence of vegetation present on scarp recovery occurred. Due to the predominance of pioneer vegetation, sand accumulation occurred faster than established shrubs, therefore a faster slumping and recovery would be expected. The profile also had larger volumes of sand due to be less impacted upon by the storm and erosive waves.

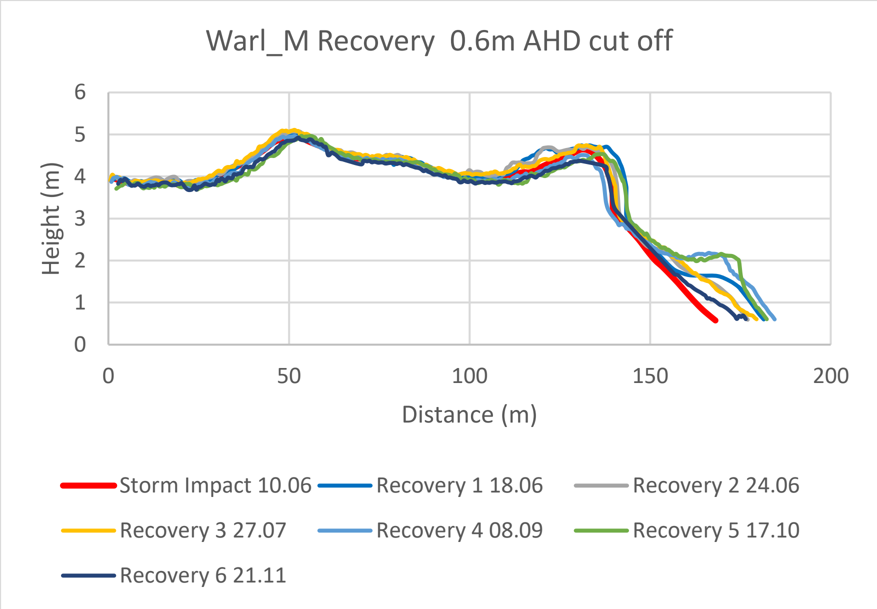
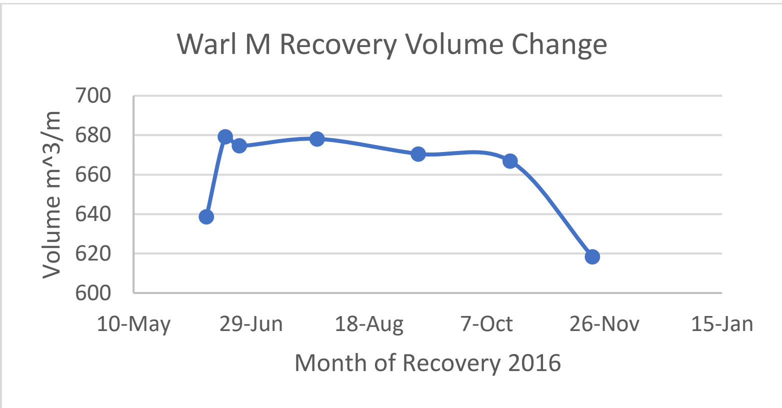
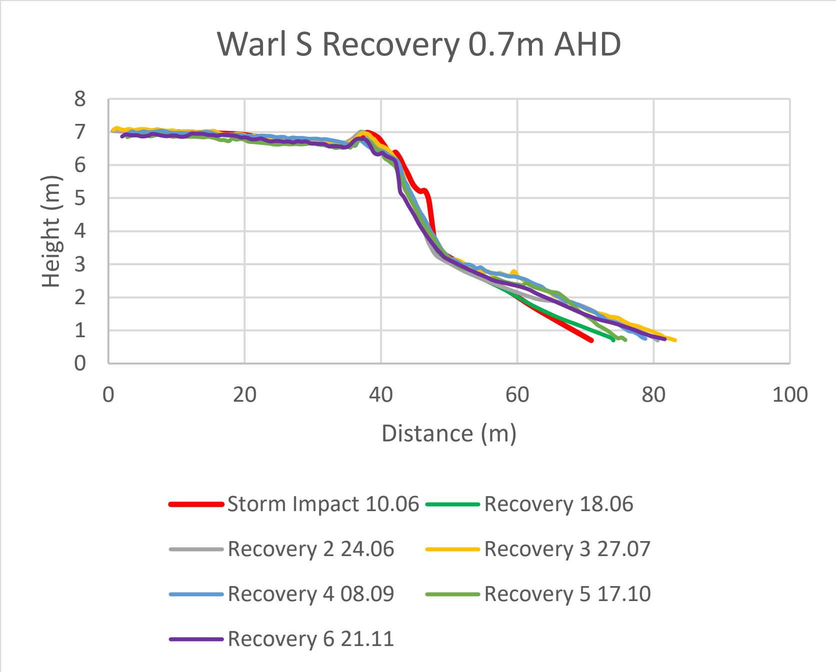


Figure 29 GPS surveys conducted at Warilla beach. Note the accretion of sand on the during recovery, and slumping of the vertical scarp to a more ramp like shape.



Month of Recovery	Volume m^3/m
10.06.2016	638.6456
18.06.2016	679.284
24.06.2016	674.6253
27.07.2016	678.152
08.09.2016	670.5589
17.10.2016	666.869
21.11.2016	618.3662

The southern profile was dominated by Cakile maritima and Ammophilia. This scarping did recover through time however, as evident with slumping, however a vertical cut is still evident with high elevation of the dune remained consistent.



Month of Recovery	Volume m^3/m
10.06.2016	343.74
18.06.2016	355.3258
24.06.2016	368.2661
27.07.2016	382.5473
08.09.2016	360.6929
17.10.2016	348.135
21.11.2016	354.98

5.2.2 Currarong Beach

Currarong beach was examined using LiDAR DEM created within ESRI's ArcMap. Profiles were generated along the beach to examine visually how recovery of the beach occurred between the LiDAR captures immediately after the storm and during the recovery period. This visual analysis provided the morphology of the beach at two certain points in time allowing the recovery of the beach to be examined, however this data capture does not provide insights into continual day-to-day and week-to-week variations which occur in the dynamic beach-dune environment. Figure (30 A) provides the spatial locations of the six profiles along the beach, overlaid upon the free access Land and Property information (LPI) imagery layer readily available online.

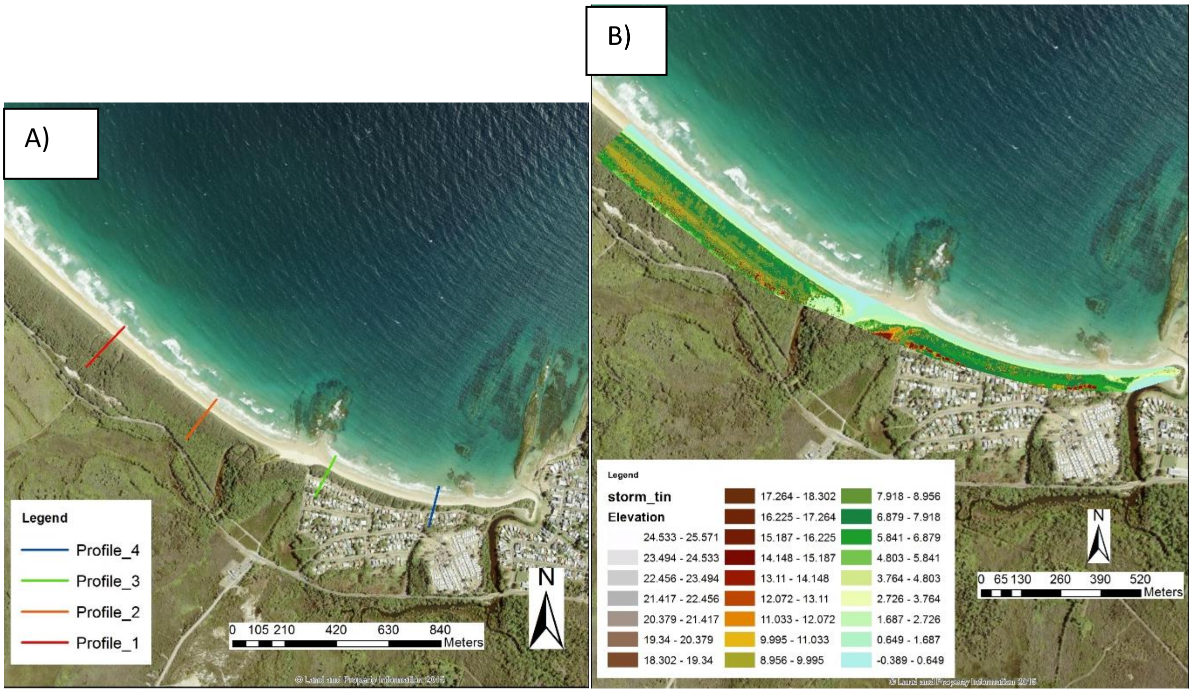


Figure 30 A) Profile Locations along Currarong Beach overlaid upon LPI Imagery Layer. B) LiDAR derived DEM of Currarong Beach immediately post storm (LiDAR provided by OEH and base imagery source LPI Imagery layer {free to access})

The immediate post storm LiDAR was transformed into a TIN DEM to examine the extent of scarping immediately upon the beach (Figure 30 B). However to effectively examine the scarping, the TIN was visualised in ESRI’S ArcScene to allow for three dimensional visual analysis of the scarping along the length of the beach. It must be noted that the immediate storm LiDAR did not receive significant processing before being visualised in this study, with high variation in elevation occurring on the most landward extent of the DEM. This variation is consistent with vegetation being captured in the dataset as well as the ground points. Vertical exaggeration was used during the visualisation of the DEM in ArcScene to highlight changes in elevation in a more effective manner.

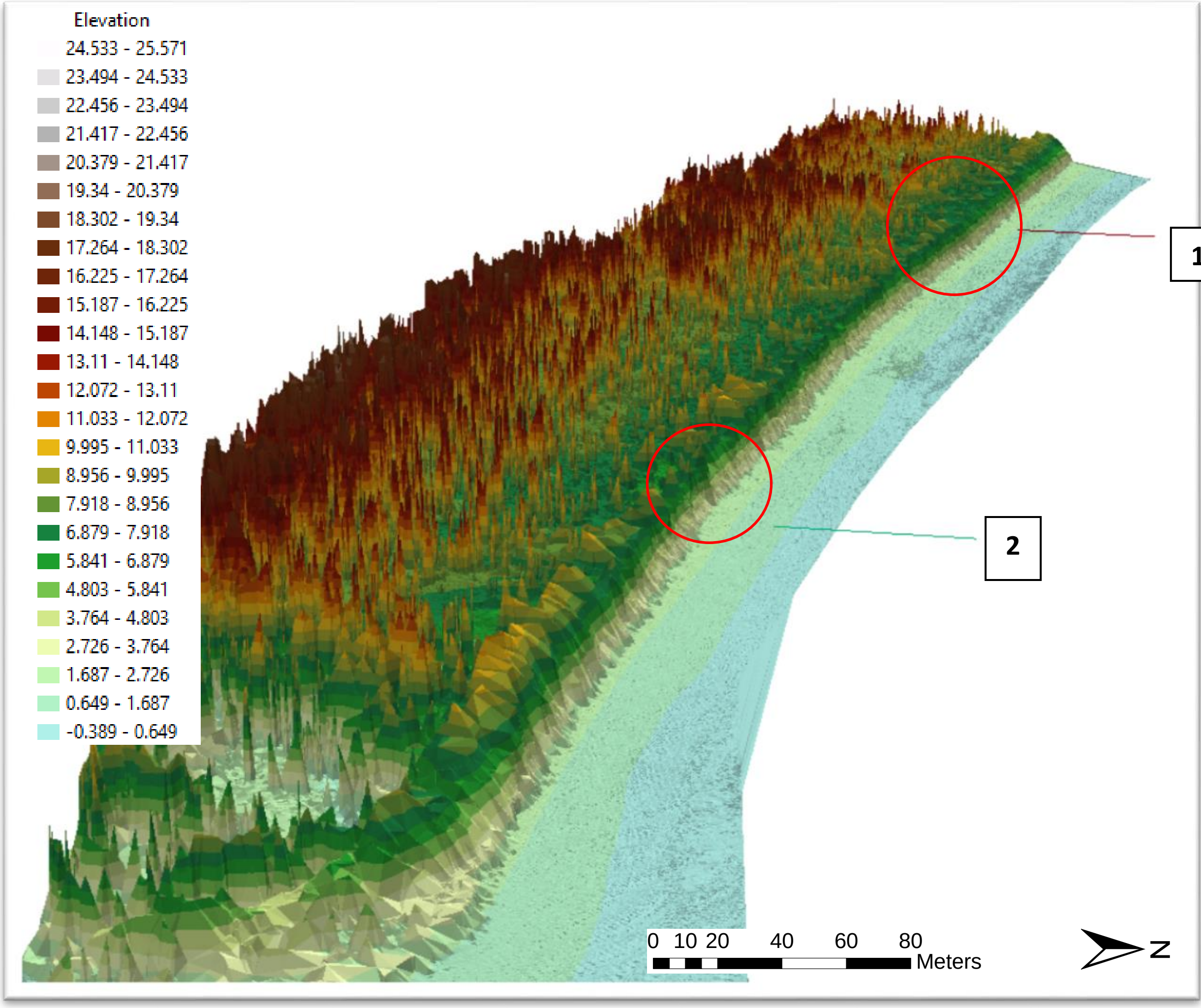


Figure 31 Three Dimensional DEM of LiDAR data captured immediately post storm showing Currarong Beach facing west. Note the elevation displayed has a vertical exaggeration of 2 to highlight scarping. The lines indicate profile locations for this beach with red circles highlighting the scarp height at each profile. Note profile 1 exhibited an elevation of 5m where profile 2 exhibited a height of approximately 6.5-7m.

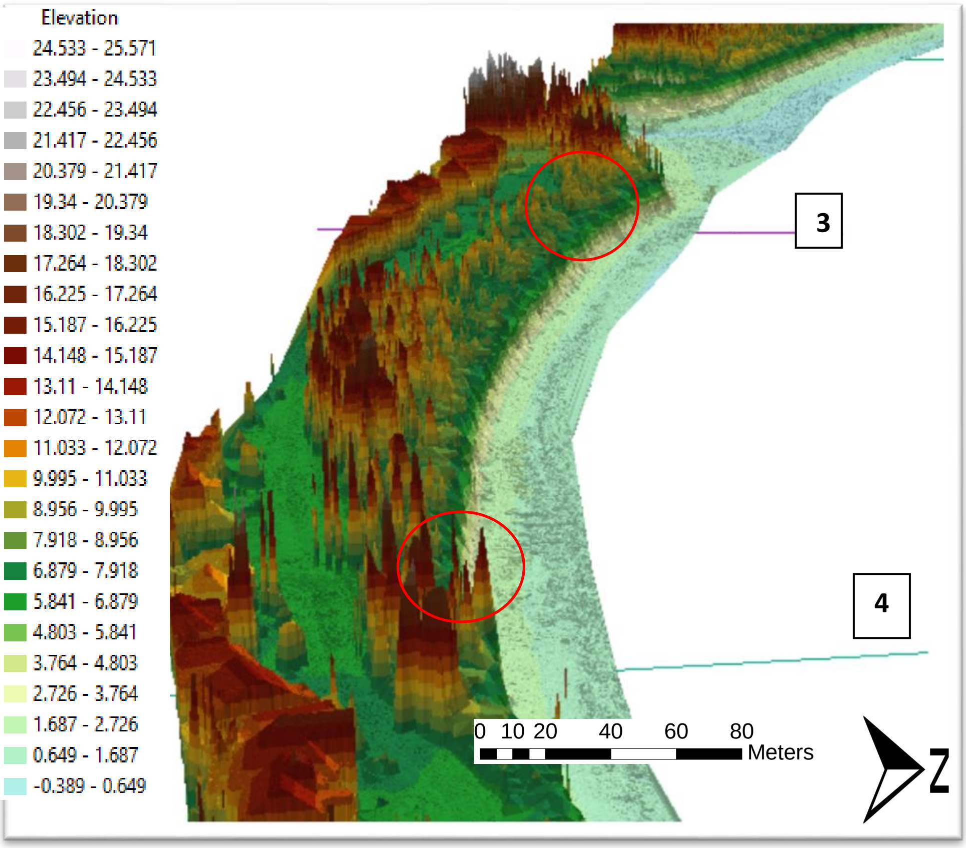


Figure 32Three Dimensional DEM of LiDAR data captured immediately post storm showing Currarong Beach facing west. Note the elevation displayed has a vertical exaggeration of 2 to highlight scarping. The lines indicate profile locations for this beach with red circles highlighting the scarp height at each profile. Note profile 3 exhibited an elevation of 5m where profile 2 exhibited a height of approximately 6.5-7m

Vegetation outliers appear to be evident within the DEM however, as seen through the larger pyramidal shapes occupying the back of the foredune. The scarp height is shown to consistently have a height ranging from approximately 5-7m.

LiDAR for the Recovery period taken by UNSW was created into a TIN DEM to examine the extent of scarping upon the beach during recovery to examine whether the scarp heights which were highest remain higher than lower scarp heights. This was done to examine the primary aim of examining whether higher scarps take longer to recover than lower scarps.(Figure 33 B). The TIN was visualised in ESRI'S ArcScene to allow for three dimensional visual analysis of the scarping along the length of the beach during the recovery period. The recovery of scarping on the foredune showed some recovery (i.e. slumping) through this period. Figure 32 shows Currarong beach looking north from the approximate middle of the beach. Across the length of the beach, the general trend of scarp height remaining mostly vertical. The scarp has appeared to show a slight decrease in height and more elevation at the toe of the dune consistent with accretion of sand, due to excavation of the channel and placement at the toe of the dune as part of Shoalhaven City Council management.

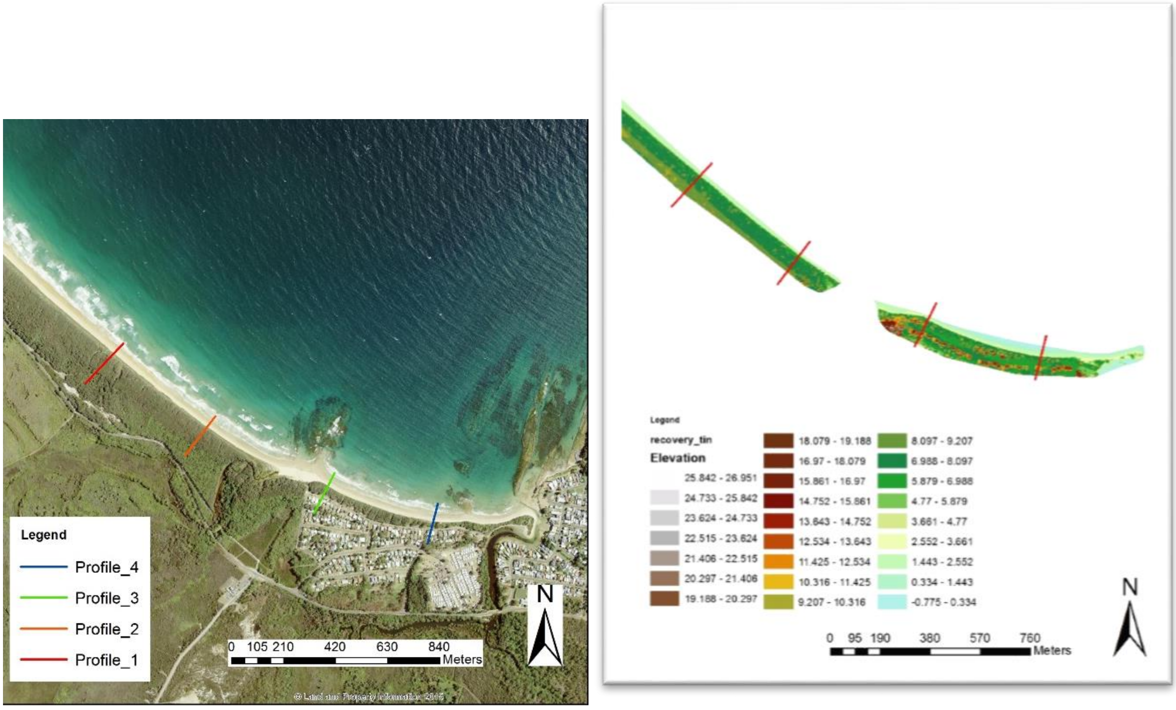


Figure 33 A) Profile Locations along Currarong Beach overlaid upon LPI Imagery Layer. b) LiDAR derived DEM OF Currarong during recovery (LiDAR provided by UNSW and base imagery source LPI imagery layer {free to access})

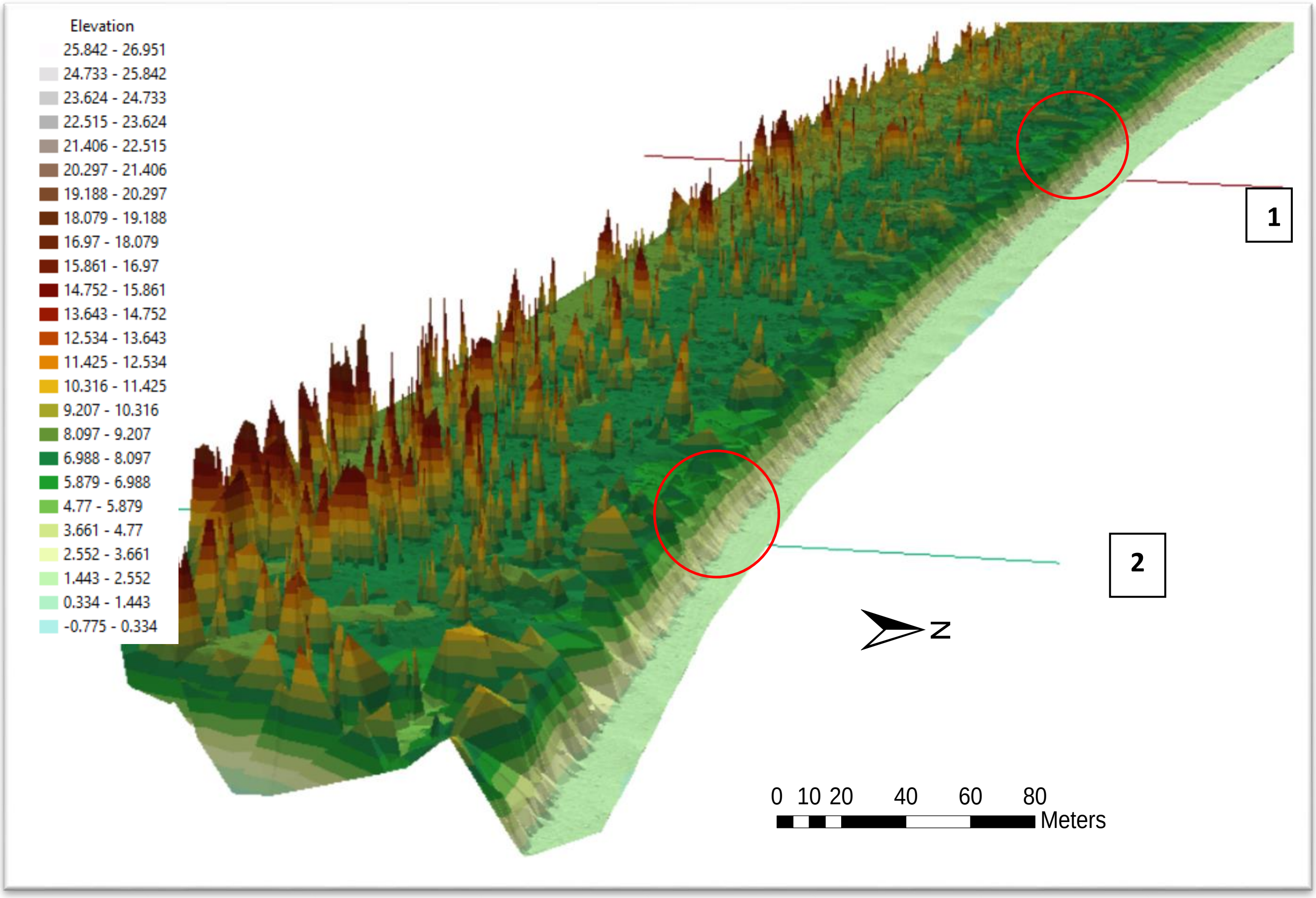


Figure 34 Three Dimensional DEM of LiDAR data captured during recovery showing Currarong Beach facing west. Note the elevation displayed has a vertical exaggeration of 2 to highlight scarping. The lines indicate profile locations for this beach with red circles

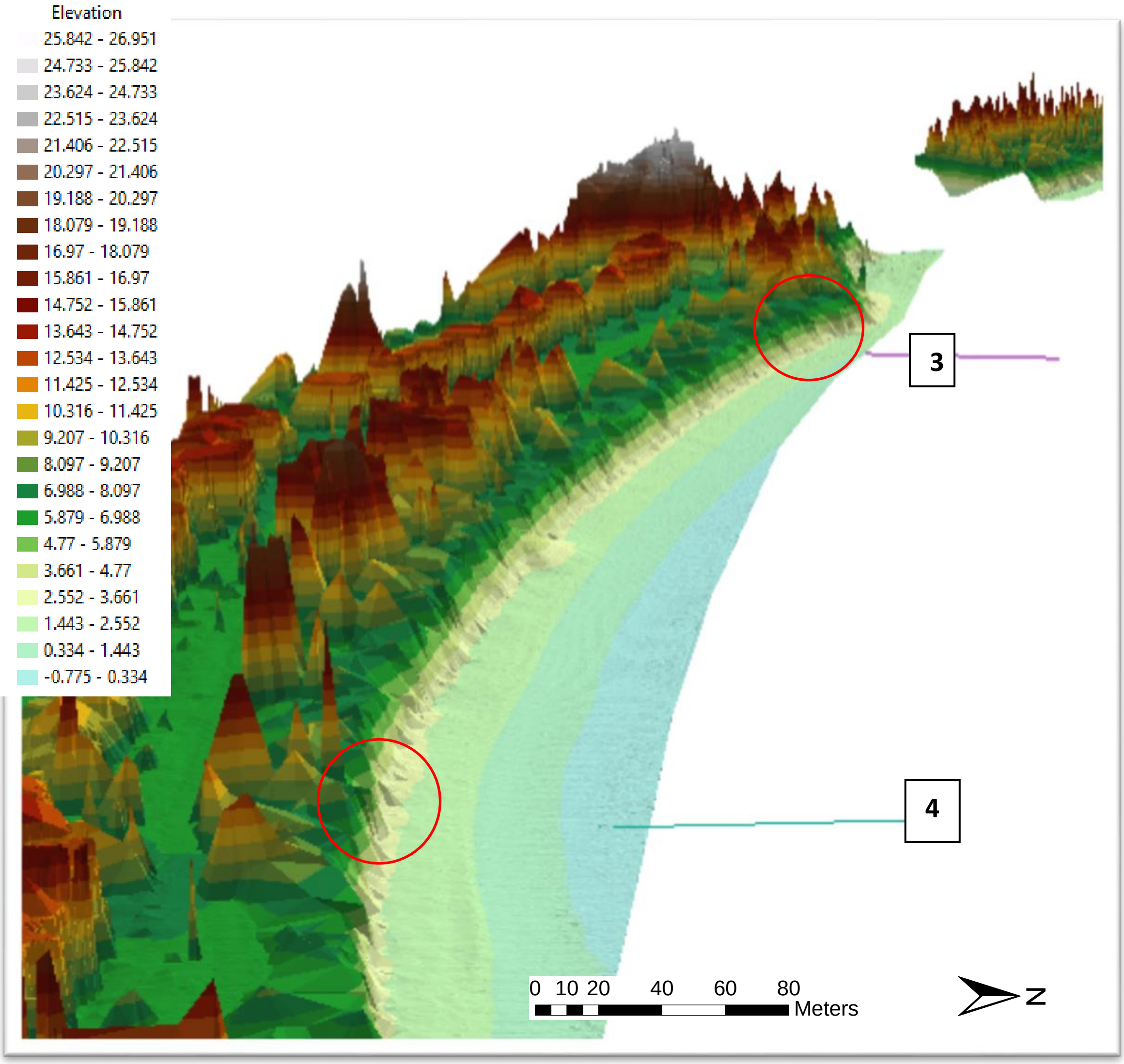


Figure 35 Three Dimensional DEM of LiDAR data captured during recovery showing Currarong Beach facing west. Note the elevation displayed has a vertical exaggeration of 2 to highlight scarping. The lines indicate profile locations for this beach with red circles

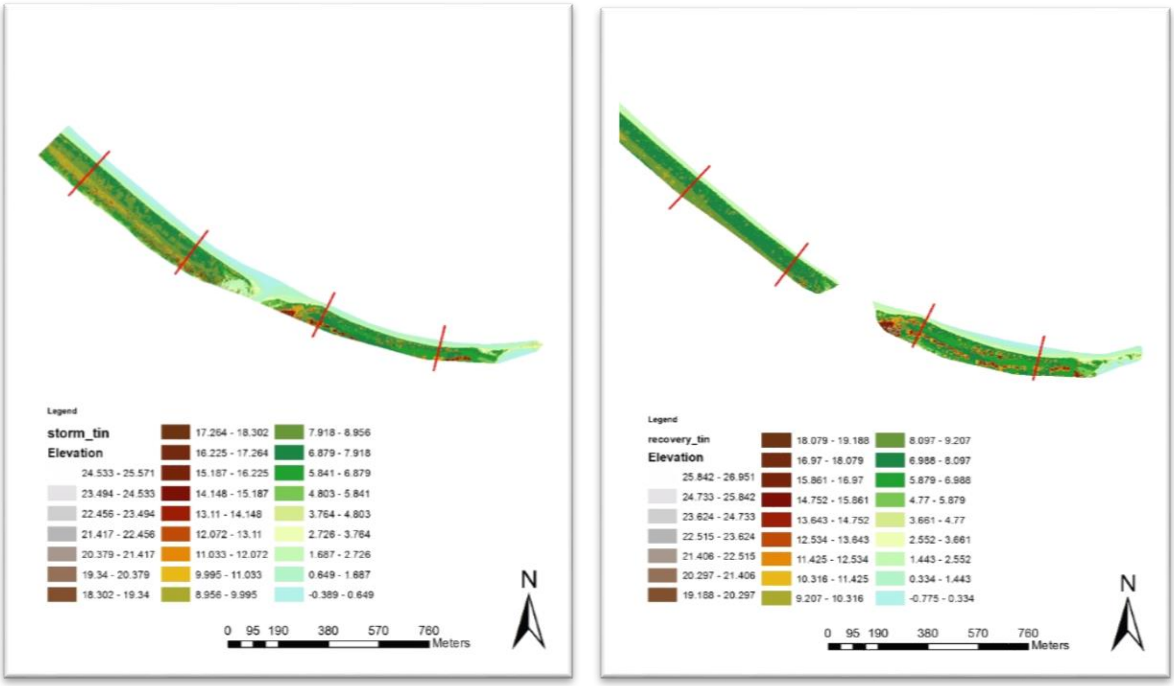
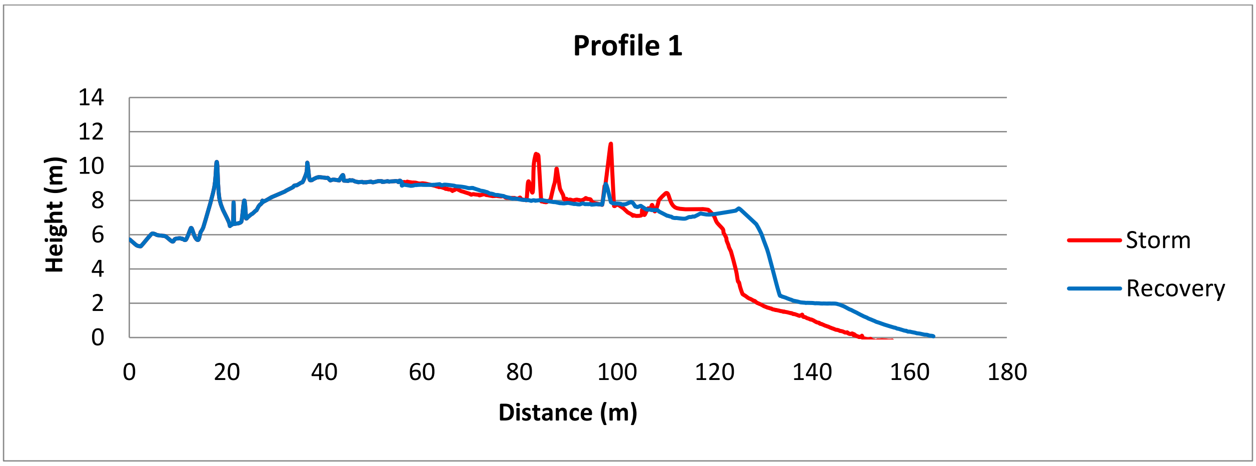
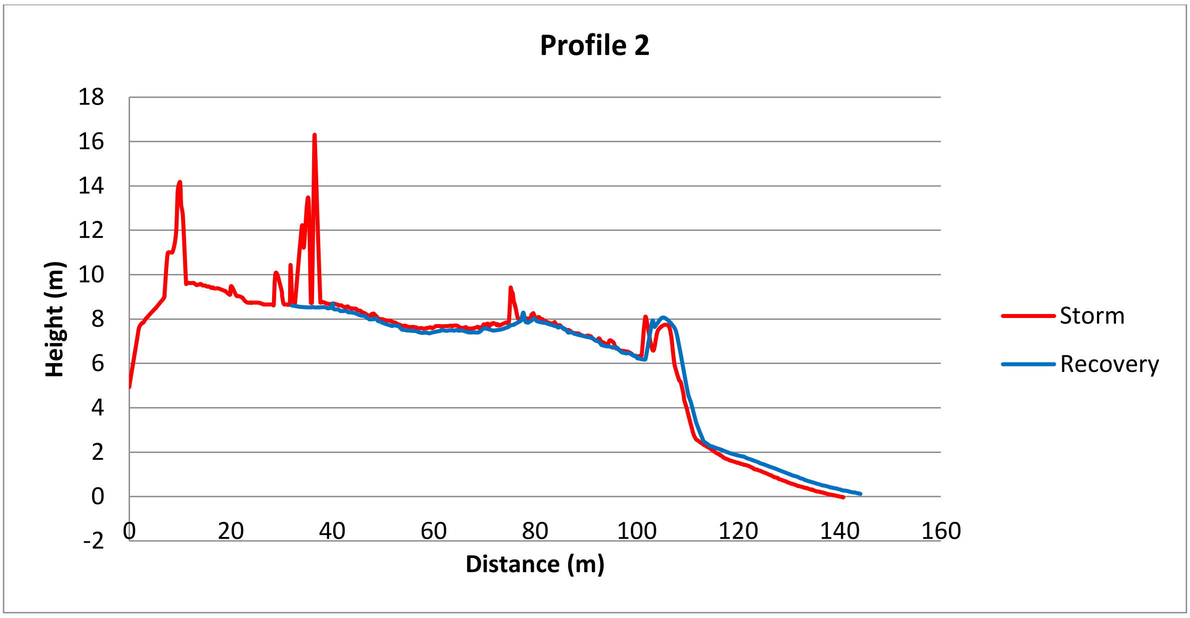
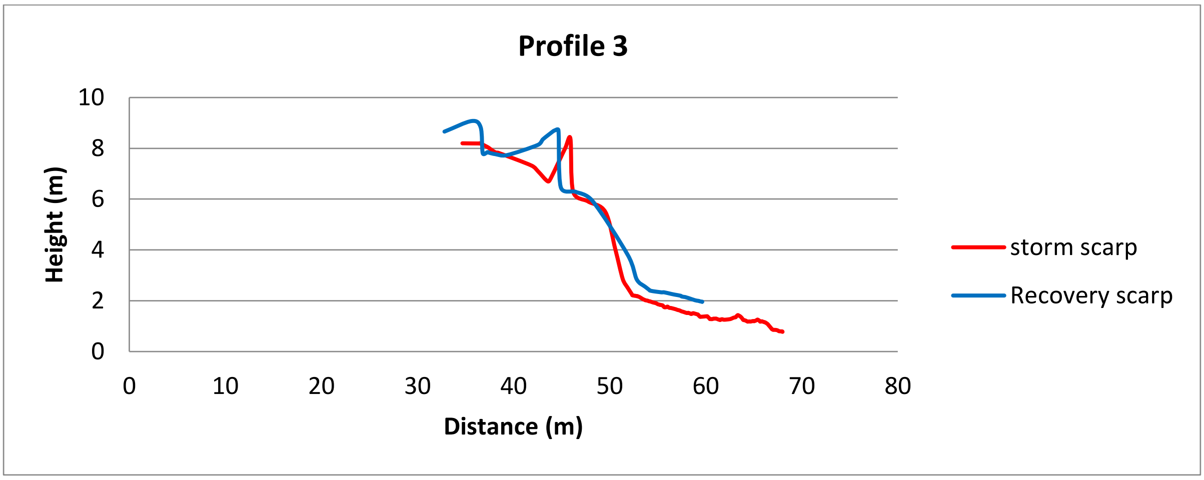
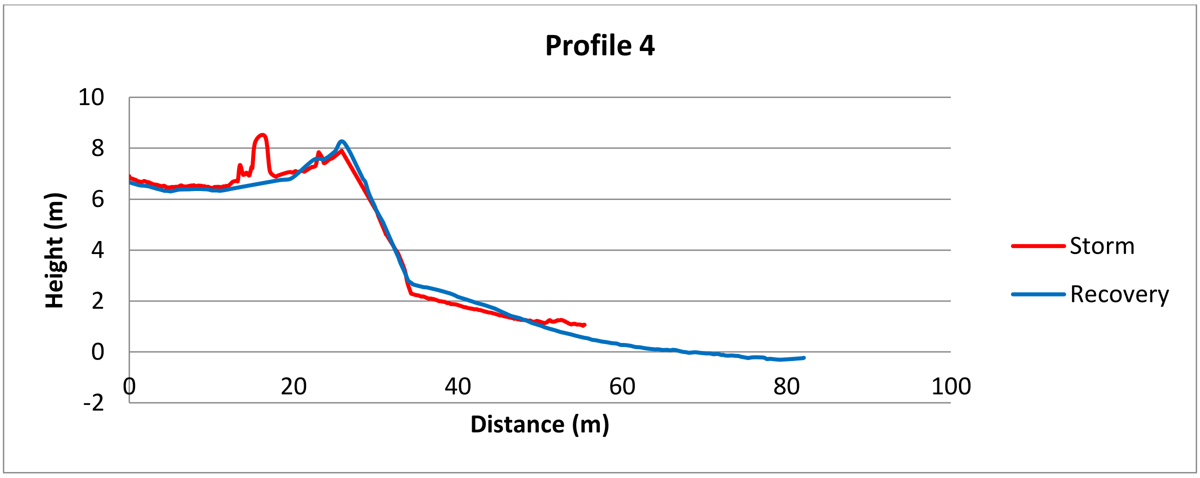


Figure 36 Storm and recovery TINs for Currarong beach with derived profile locations.




Profile 2
Height (m)
18
16
14
12
10
8
6
4
2
0
-2
0
20
40
60
80
100
120
140
160
Distance (m)
Storm
Recovery


Profile 3
Height (m)
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
Distance (m)
storm scarp
Recovery scarp


Profile 4
Height (m)
10
8
6
4
2
0
-2
0
20
40
60
80
100
Distance (m)
Storm
Recovery

The profiles at Currarong displayed various stages of dune scarp recovery. All four LiDAR derived profiles displayed a vertical cut to varying degrees, with some slumping occurring, and also evident, accretion on the berm. The height of scarping between the profiles remained consistent at approximately 6-7m at the highest points. Some slumping naturally can be seen throughout the profiles, particularly profile 3 where the ramp like shape of the scarp is evident.

These high scarps have not reduced significantly in height, and have retained the vertical shape to a larger degree than smaller scarping present at other beaches. The presence of shrubs including *Acacia var. sophorae* and *Leptospermum laevigatum* along the scarping may present a trend that due to a lack of pioneer vegetation to trap sand more effectively than shrubs, the scarp may take retain its shape and height for a longer time period. Therefore, the LiDAR derived profiles due to consistent vertical shape and minimal height difference between post-storm and recovery LiDAR supports the hypothesis that higher scarps take a longer time period to recover.

5.2.3.Bengello Beach

Bengello beach was examined using LiDAR DEM created within ESRI's ArcMap. Profiles were created along the beach to examine visually how recovery of the beach occurred between the LiDAR captures immediately after the storm and during the recovery period. This visual analysis provides the morphology of the beach at two certain points in time allowing the recovery of the beach to be examined, however this data capture does not provide insights into continual day-to-day and week-to-week variations which occur in the dynamic beach-dune environment. Figure (37 a) provides the spatial locations of the four profiles along the beach, overlaid upon the free access Land and Property information (LPI) imagery layer readily available online.

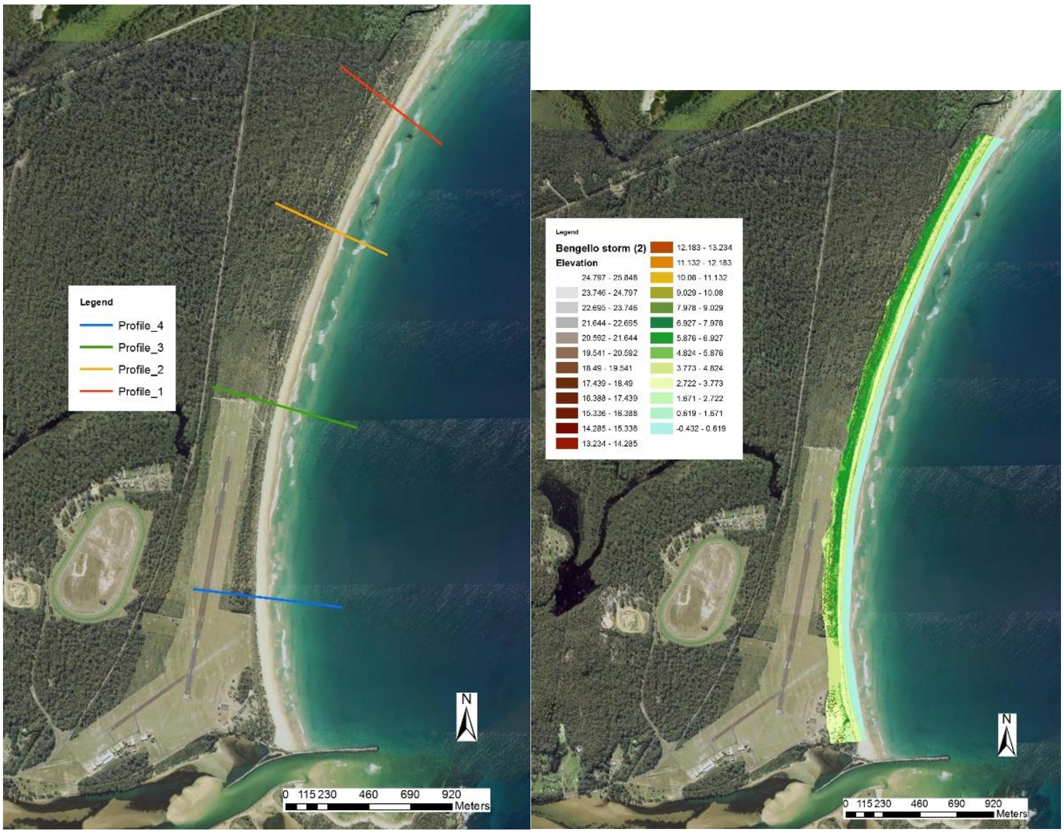


Figure 37 A) LiDAR profile locations at Bengello beach. B) Post-storm DEM at Bengello beach

Storm scarping was not as significant at Bengello beach with a scarp of approximately 4m. The scarp for the southern end of the beach studied did not vary particularly in height and displayed a small vertical cut. This beach varied from Currarong and Warilla by having a smaller scarp with minimal height variation.

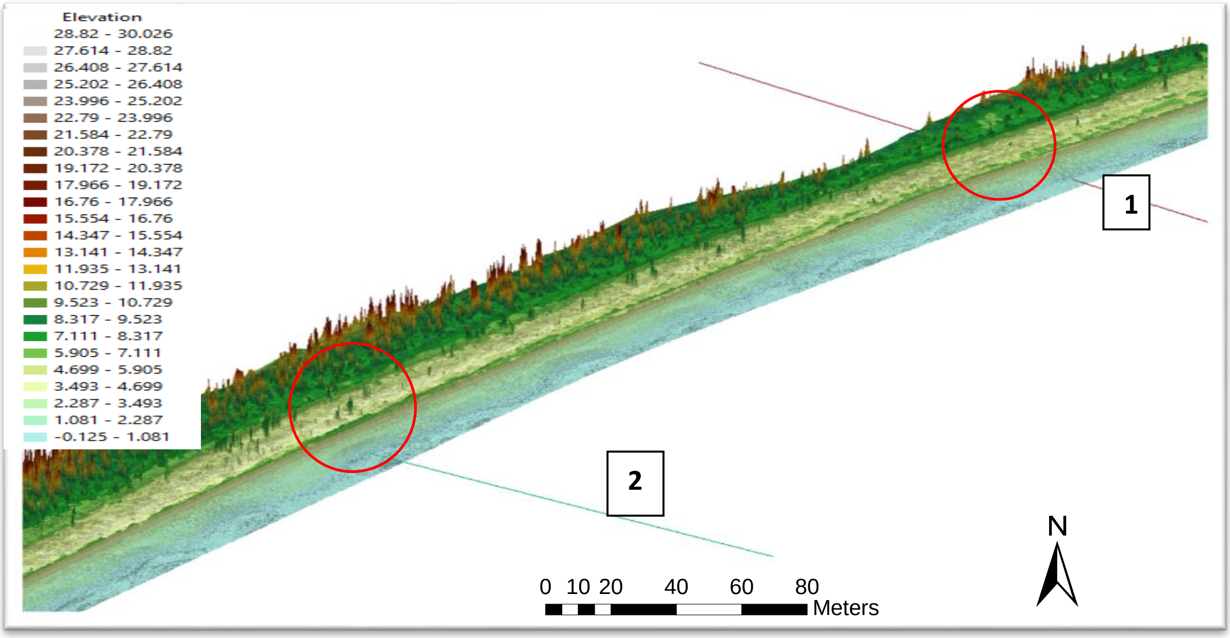


Figure 38 Three Dimensional DEM of LiDAR data captured immediately post storm showing Bengello Beach facing North. Note the elevation displayed has a vertical exaggeration of 2 to highlight scarping. The lines indicate profile locations for this beach with red circles

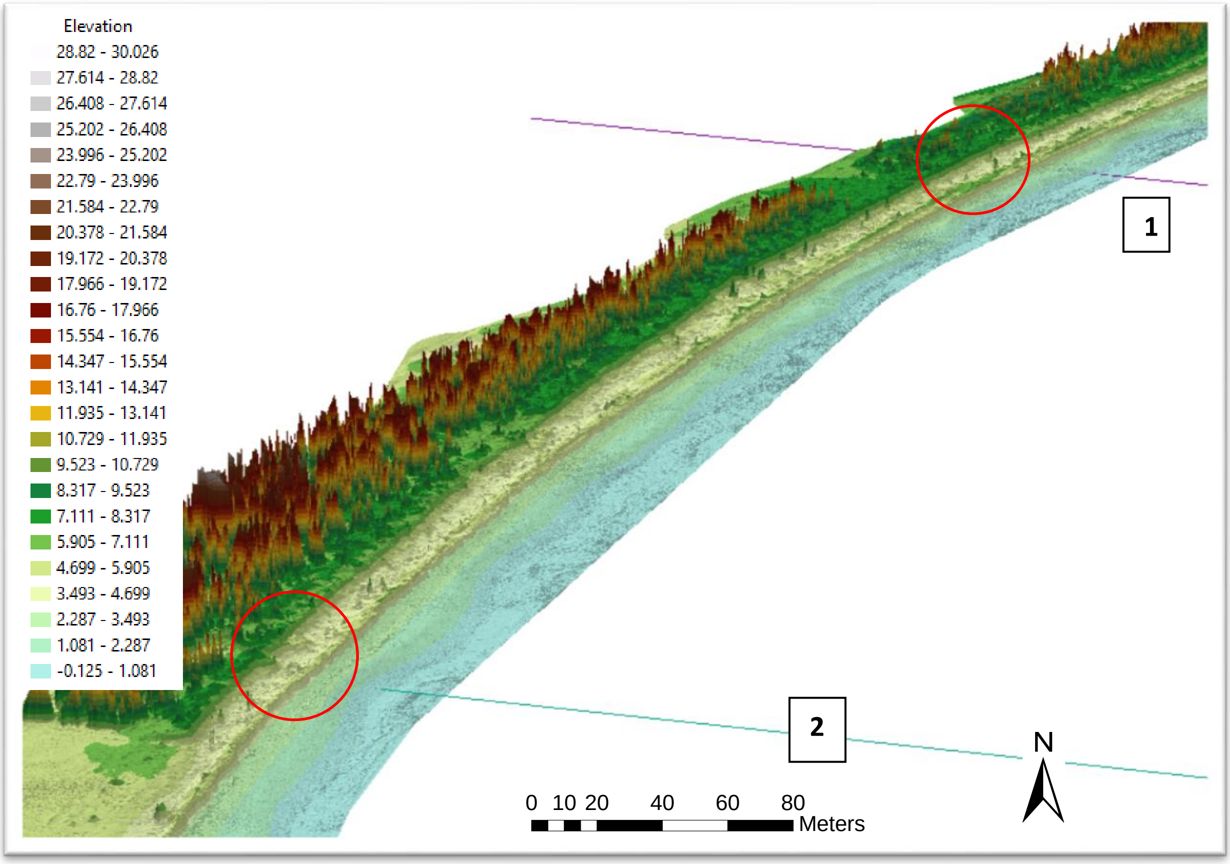


Figure 39Three Dimensional DEM of LiDAR data captured immediately post storm showing Bengello Beach facing North. Note the elevation displayed has a vertical exaggeration of 2 to highlight scarping. The lines indicate profile locations for this beach with red circles highlighting the scarp height at each profile. Note profile 3 exhibited an elevation of 5m where profile 2 exhibited a height of approximately 6.5-7m

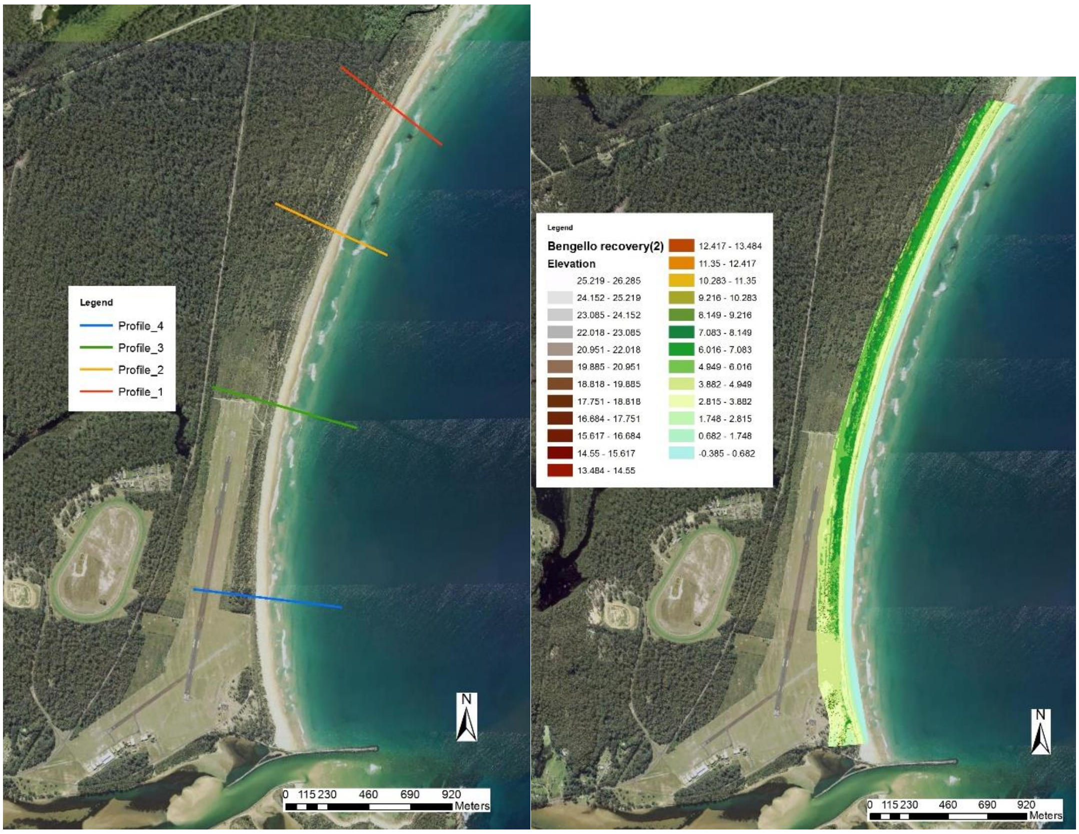


Figure 40 LiDAR derived profile locations and recovery LiDAR at Bengello Beach

The recovery LiDAR was visualised in ArcScene and displayed slight slumping of scarping, with a decrease in height evident. Scarp height during the November LiDAR run was consistent around 3m along the southern reach of the beach.

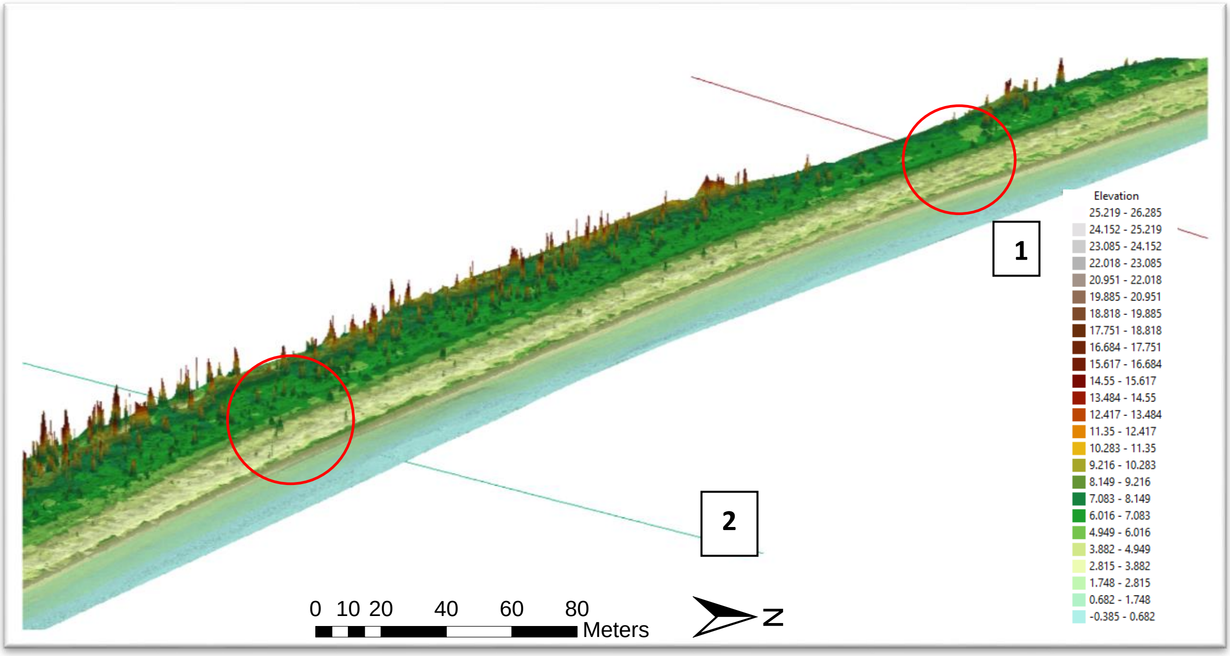


Figure 41 Three Dimensional DEM of LiDAR data captured during the recovery period showing Bengello Beach facing north. Note the elevation displayed has a vertical exaggeration of 2 to highlight scarping. The lines indicate profile locations for this beach with red circles highlighting the scarp height at each profile. Note profile 3 exhibited an elevation of 5m where profile 2 exhibited a height of approximately 3m

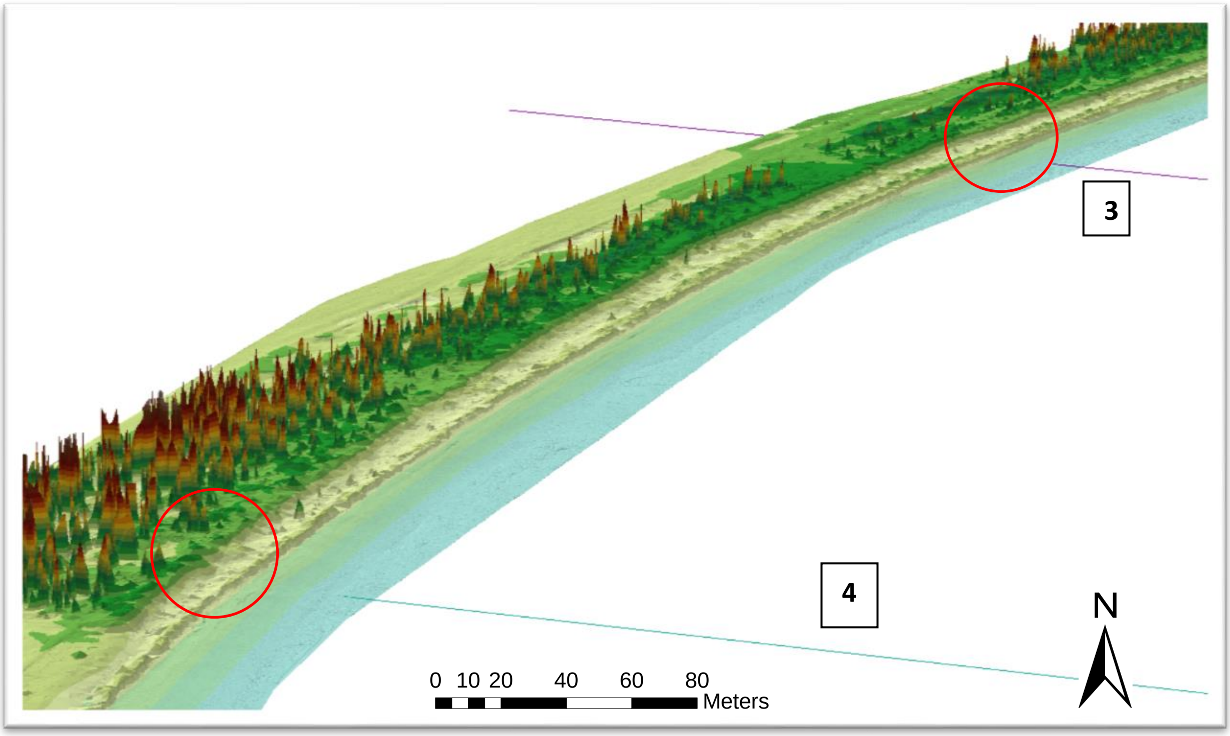
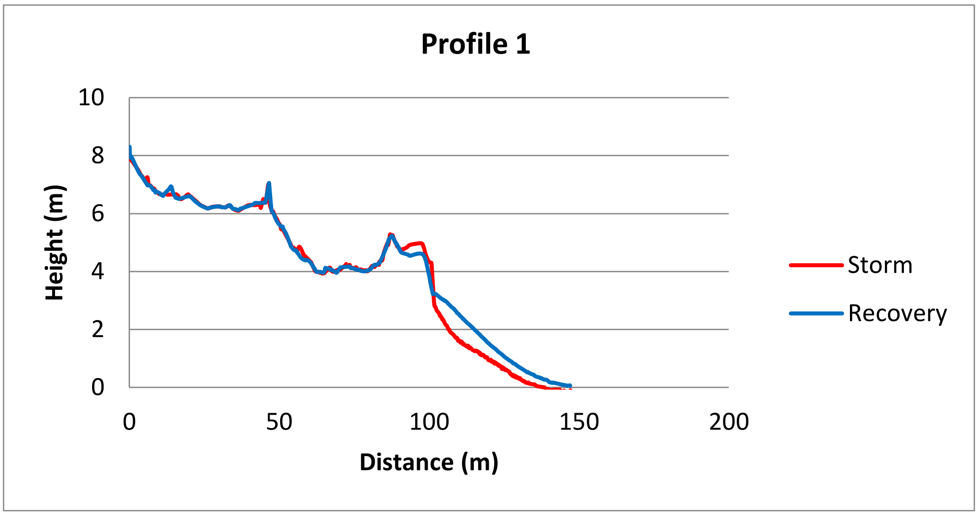
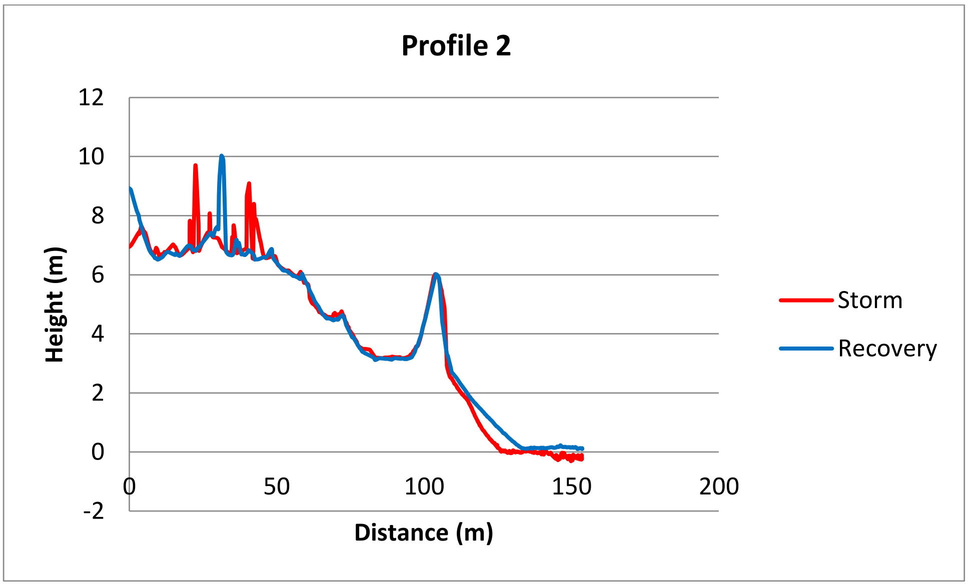
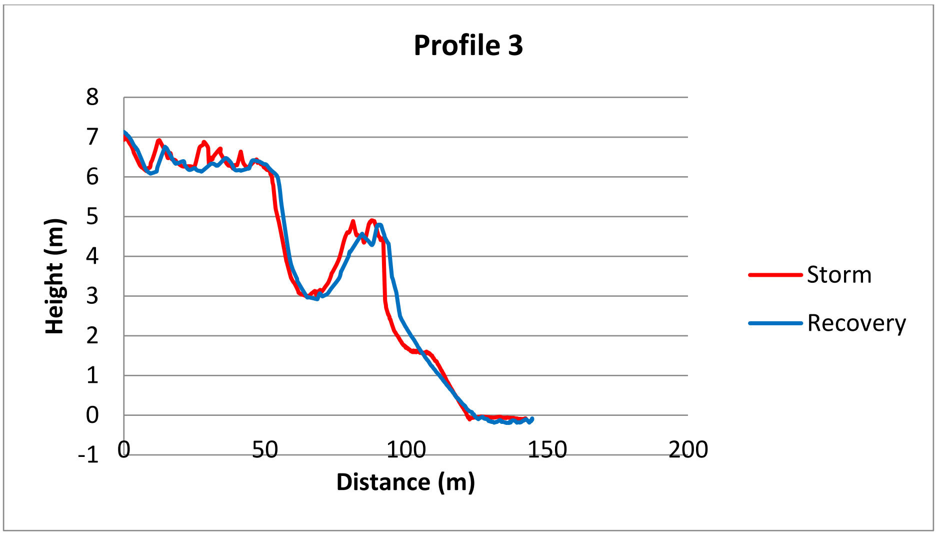


Figure 42 Three Dimensional DEM of LiDAR data captured during the recovery period showing Bengello Beach facing north. Note the elevation displayed has a vertical exaggeration of 2 to highlight scarping. The lines indicate profile locations for this beach with red circles highlighting the scarp height at each profile. Note profile 3 exhibited an elevation of 5m where profile 2 exhibited a height of approximately 3m.

To best examine scarp recovery between the LiDAR sets, the ‘point profiler tool’ was used to display the profile height beginning at the back of the foredune and finishing at the most-seaward section of the tin. This allowed for visual evidence of beach recovery which is not clear from examining the 3d DEM. The profiler tool was drawn over each TIN at the 4 profiles producing profiles for visual examination.







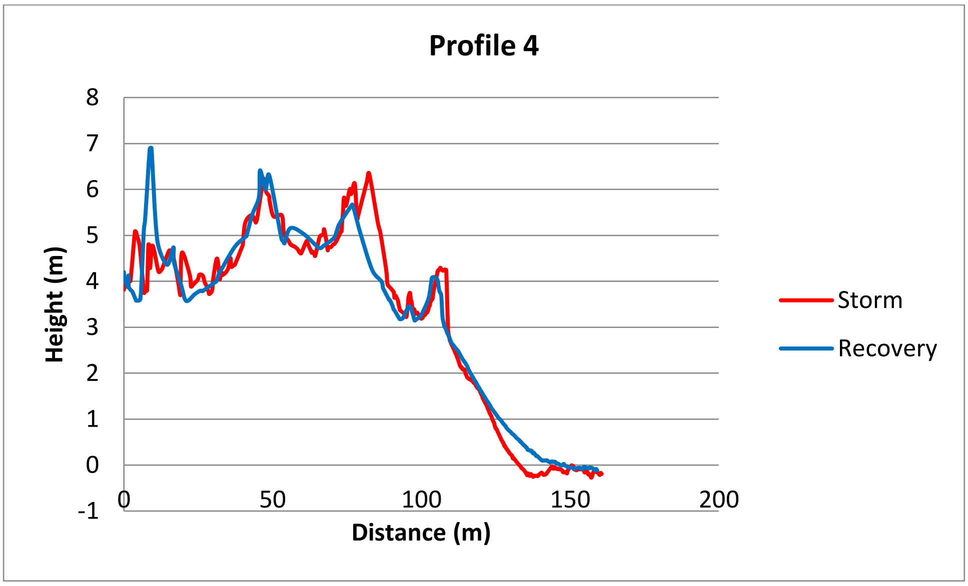


Figure 43 profiles 1-4 derived from LiDAR AT Bengello

The profiles derived show the scarping had slumped at all profiles. Whilst there was still a section of a vertical cut evident in each profile (note particularly profile 3), the cut was not as pronounced through. Moreover the beach berm had accreted sand during recovery at all profiles.

5.3 Summary

LiDAR data combined with surveying using RTK GPS was used to examine if higher scarps take longer to recover than smaller scarps. It was evident that higher scarps tended to retain a vertical cut for longer with less slumping. This was seen at Currarong where shrubs dominated the scarp line and the vertical cut was retained for a greater period of time. Small scarps slumped at a faster rate where pioneer grasses were present with some incipient dunes beginning to form.

6. DISCUSSION

The purpose of this chapter is to discuss the significance and usefulness of mapping erosional scarping and studying vegetation composition on dune systems as a result of ever increasing storm activity resulting from predicted climate change. The chapter will begin by outlining and discussing the relevant storm characteristics and impacts upon different systems containing numerous vegetation species. This will be followed by a discussion of whether the June 6th event is to be considered a major event for future storm comparison and evaluation. This will be followed by an examination of the recovery of different beach-dune systems according to the dominant vegetation. This will also involve a more detailed look at beaches which were profiled after the storm to attempt to determine how recovery was influenced by vegetation on beach systems and within beach systems. The chapter will then conclude with determining the relevance of this study to coastal management and the implications of the methodologies that were employed.

6.1 Photographical examination of storm impact and recovery

Widespread erosion of the coastal region resulted from the June 6th storm event impacted upon the coastline. The erosion of NSW beaches was exacerbated by the storm coinciding with the winter solstice spring tide (king tide) which exacerbated. The east coast low produced high swell and high winds, with these winds producing locally generated waves which when combined with the unusually high tide, created a highly erosive event for NSW beaches. The destructive nature of the storm was seen through significant erosion of beaches, particularly the southern ends due to these beaches having a north-east aspect, with the storm coming from the north-east. Erosion impacts occurring on particularly the southern ends of beaches was seen through mobilisation of sand from the beach and foredune, which was subsequently transported offshore. This process resulted in prominent scarping of beaches, with vegetation removal, exposure of vegetation root systems and slumping of vegetation on the foredune.

Photographical evidence of the storm impact provides a beneficial record of storm impacts which is important for effective coastal management practices. By employing photographic records of beaches before large storm events, and then immediately post large events and during recovery, impacts and risks of storms and the recovery process are documented. These records prove useful in preparing management plans to help mitigate impacts of future storms.

The NSW OEH provided the majority of the photographical evidence of the immediate post-storm impact upon the case study beaches presented in this study. The photographs provided by Aimee Beardsmore and Daniel Wiecek provided detail of the extent of erosion and the height of scarping beach-dunes systems. This allowed for visual examination to determine whether the height of scarping influences the time taken for the scarp to recover, which was one of the primary aims of this study.

Scarping height ranged across the study beaches, with the consistent trend noted that the southern ends of beaches had greater scarping height. Scarping was the most prominent impact of the June 6th storm event. The photographic evidence showed the scarp height immediately after the event providing sufficient detail of scarp shape and height to allow for a visual comparison of the scarp at later stages in recovery. Comparing this with recovery photographs taken provides visual evidence of scarp slumping and recovery.

Currarong beach experienced high scarping reaching up to 6m. The prominent cut did slump during the recovery period, however as evident in Figure 44, the scarp did retain a steep height during the slumping process.

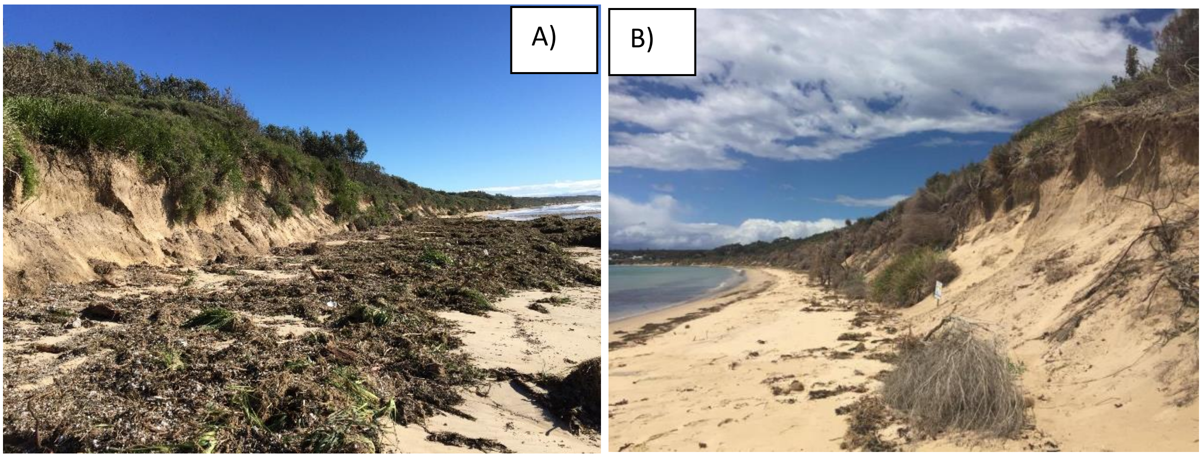


Figure 44A)Extensive scarping present at the southern section of Currarong beach on June 8th 2016 looking north-west (Photo Source: Aimee Beardsmore, OEH, 2016) B) Scarping at Currarong during recovery looking south-east. Note slumping in fore ground of recovery image. (Photo source: Author, October 19th 2016).

Also evident in the storm and recovery photos is the slumping of vegetation during the recovery process. The storm impact saw the removal of vegetation and placement on the berm during sand mobilisation in the erosion process (Figures 44A and 44B). During the recovery process, the photos indicate vegetation has continued to move down the slope towards the berm as sand stability on the slope decreases during slumping. This also has exposed root structures during movement down slope.

Figure 45 Walkway undercutting and destruction at Currarong beach (6th of June 2016). Note vegetation removal and undercutting. (Source: Ray Massie, Shoalhaven City Council, 2016)

Figure 46 Scarp slumping on October 19th at Currarong. Note loss of vertical cut and accretion of sand at toe of dune (Photos taken by Author)

Shoalhaven City Council implemented post-storm management strategies of beach and dune nourishment, due to the safety concern regarding the high nature of the scarping. The works aimed to address the storm scarping present on the beach, in conjunction with addressing undercutting of walkways and damage to beach access structures. This involved Shoalhaven City Council scraping sand from the low tide beach near Warrain Crescent, in conjunction with excavation of sand from the creek inlet, which resulted in sand being placed at the toe of the erosional scarp (Shoalhaven City Council, 2016). The access stairs were also replaced

(Figure 45 and 46). This remediation work occurred at only a section of the beach near the intersection of Worrigee road with Warrain Crescent, where scarping was most severe.

Similarly, Warilla beach was extensively eroded at the southern end with exposure of the rock wall. Undercutting of walkways at the southern end was also evident with damage to the dune fencing observable within the photographic evidence. Dune scarping was highest at the southern end of the beach where the rock wall was exposed. The scarping decreased in height from the centre of the beach heading north. As evident in Figure 47, the smaller scarp height present at the northern ends of the beach has appeared to have recovered faster. This recovery is demonstrated through the slumped scarp in Figure 47, and a loss of a vertical cut. Also apparent during this process is the establishment of pioneer vegetation at the base of the dune indicating the beginning of sand trap to potentially form an incipient dune with further sand accretion.

Figure 47 A) Warilla beach looking north from the centre of the beach on the 7th of June. Note the erosional scarp present which decreases in height towards the northern end. (Photo by Daniel Weicek, OEH); B) Dune scarping at Warilla beach in October. Note the vertical cut present in A) has become less pronounced with pioneer vegetation forming at the toe of the dune (photo taken by Author, October 19th 2016).

By examining photographic evidence, trends appear to support the hypothesis that scarp height does influence the time taken for recovery. Through examining the most affected southern ends of beaches where scarping was highest, with the lesser affected middle to northern ends, the photographic evidence displayed a possible trend that higher scarp heights e.g. Currarong beach, between the photos taken at June and October, retained a vertical cut for longer, with less slumping to reduce height of the scarp occurring. The northern ends e.g. Warilla, displayed a smaller scarp height with a less vertical cut and the possible formation of an incipient dune beginning to occur.

6.1.1 Limitations

Whilst photographical evidence provides a decent visual assessment of scarp shape and height immediately post storm and during recovery, it does not provide quantifiable data to assess volume change such as through surveying. Therefore, photographic evidence of storm impact should be supplemented with methods such as surveying and LiDAR to best examine how storms impact upon dunes cause scarping, and monitoring the recovery process. Comparing photographs can also be limited due to the photographs not capturing key differences in profiles, for example management strategies undertaken to artificially slump the scarp.

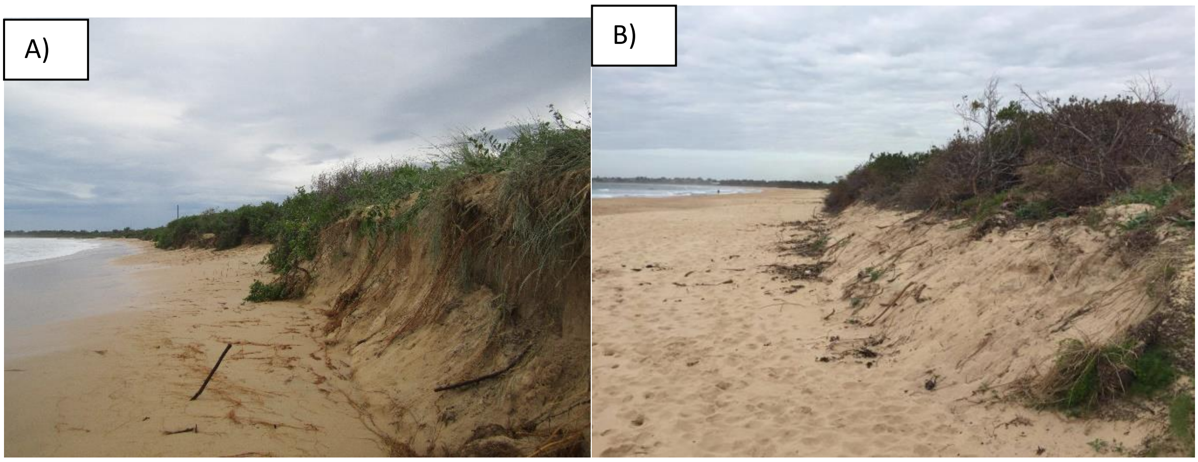


Figure 48 A) Woonona beach looking south on June 6th (Photo source: Aimee Beardsmore, OEH, 2016). Note vertical scarping. B) Slumped scarp on September 8th 2016 (photo taken by Author)

When examining the two photographs showing different points along scarping at Woonona beach, the detail of artificial slumping (excavators used to flatten the scarp and induce recovery) of the scarp on June 28th is not evident, however just a slumped scarp is depicted. This highlights the importance of all stakeholders such as local councils and relevant state bodies such as the OEH in communicating and collaborating on management strategies, ensuring incorrect assumptions are not made regarding works undertaken. For the most effective management of beaches during recovery supplementing photographical records with other methods of determining dune-beach change such as GPS surveying, can show more clearly the story of beach recovery as major details regarding scarp shape can be inferred correctly.

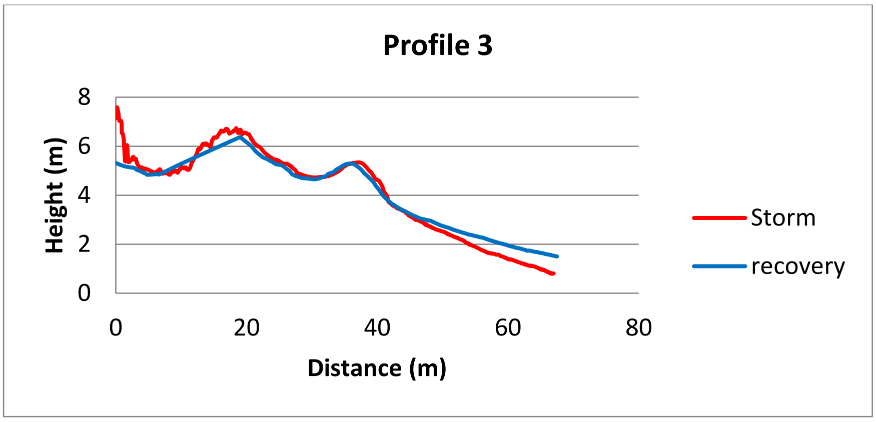
6.2 LiDAR derived Beach profiles and DEM

LiDAR is an effective tool for coastal managers to study beach-dune systems by examining the morphology of systems before and immediately after storms to gain an understanding of impacts such as dune scarping. LiDAR also makes time sensitive and potentially dangerous needs such as surveying during storm events redundant. LiDAR digital elevation models provide coastal managers with accurate topographical data for beach profiles and are also useful for determining sediment volume fluctuations.

The two sets of LiDAR used in this study were taken immediately after the June 6th event, and in November during the recovery period. This LiDAR capture immediately post-storm is an emerging capability to determine the impact of storms upon NSW beaches. This study is one of the first studies to use and display beach-dune system morphology after the June 6th storm to ascertain the extent of impacts such as erosional scarping. Integrating LiDAR runs immediately post-storm into coastal management in response to storms may provide coastal managers with detailed evidence of storm impacts and when compared with recovery runs, can be used for visual assessment of scarp recovery through time.

The LiDAR sets were transformed into TIN DEMs and using the point profiler tool, were used to examine alongshore variability at the study beaches where both sets of LiDAR were available. This was used to address the primary aim of this study to determine if scarp height has an influence on length of recovery. The LiDAR derived profiles reflected photographic observations that scarp height immediately after the storm was highest at the southern ends of the beaches. These southern ends of the beaches were stripped of pioneer vegetation with shrubs mainly present along the scarp lines (as seen through photographic evidence). Through the use of the point profiler tool, the DEM allowed for visual representation of recovery of the scarp through slumping (naturally and induced e.g. Woonona).

The LiDAR profiles were compared for the northern and southern ends of beaches. These profiles indicated accretion through the seaward building of the beach, whilst also showing smaller scarping at the northern and central sections of the beach. As evident from comparing profiles 3 and 5 at Warilla beach, the LiDAR shows that the smaller scarping and smaller vertical cut at profile 3 was not obvious in the recovery LiDAR derived profile in November. However profile 5 where scarping was higher, still retained some of the vertical shape, with height decrease not significant during the natural slump process (Figure 48).



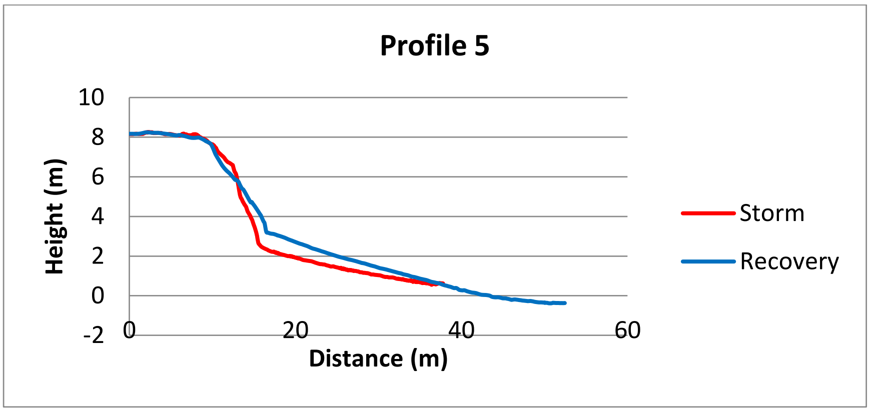


Figure 49 LiDAR derived profiles 3 and 5 at Warilla beach. Note the retention of vertical cut in scarp five through both LiDAR profiles, but greater slumping in profile 3.

LiDAR TIN DEMs allowed for three-dimensional viewing of the topography of the beach-dunes systems in both the immediate post-storm LiDAR and recovery LiDAR through ESRI's Arcscene. This allowed for an examination of scarp height throughout time in a more detailed view (Figure 48), as opposed to the two-dimensional TIN DEM map which does not capture the power of LiDAR in displaying elevation changes through time (see Figure 16 in results). However, whilst this visualisation is effective in highlighting areas of change between the post-storm and recovery DEMs, the presence of vegetation producing "pyramids" in the DEM (Figure 49) highlight how LiDAR needs to be processed to ensure no inconsistencies when examining ground based points. However, when purely examining erosional scarps, this issue is not paramount.

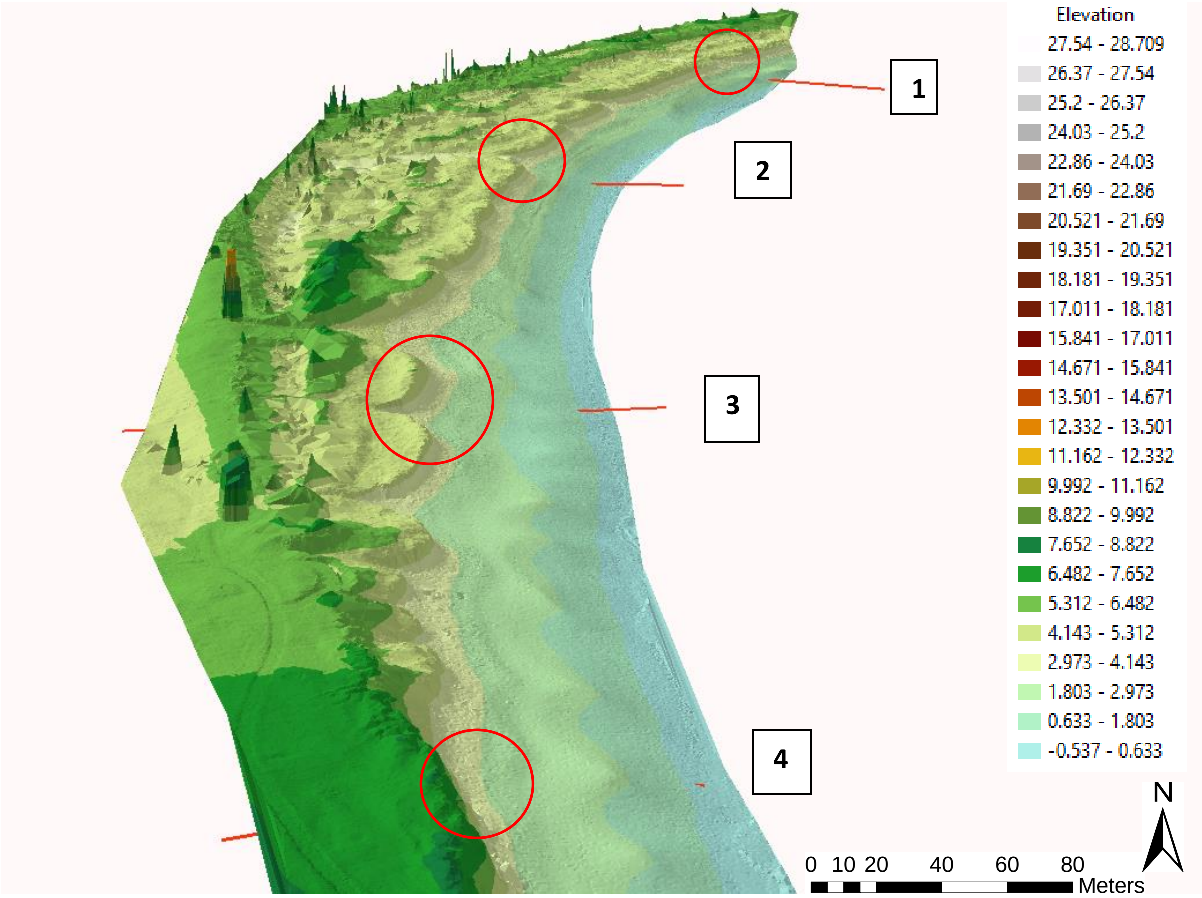


Figure 50 Three Dimensional view of Warilla beach looking North derived from LiDAR DEM of data captured in November by UNSW. Vertical exaggeration of 3. Note the presence of "pyramids" at the hind dune area displaying high elevation.

The use of LiDAR to produce profiles to examine morphological features and scarping of beaches is a powerful and effective tool for coastal managers. It allows for coastal managers to examine morphological features present in beach-dune systems immediately after storm events, and during the recovery period to assess how beaches respond to storms of certain magnitudes. It allows for a greater understanding of storm impacts such as dune scarping, without time sensitive needs such as surveying in potentially dangerous conditions to ascertain volume change.

The LiDAR used in this study provided detailed visual representation of scarping change from the immediate post-storm capture, to the recovery capture. The LiDAR indicated a trend that higher scarps retained a more vertical cut, and higher elevation for longer in comparison with smaller scarps which tended to slump faster during the recovery process and lose vertical shape. This trend was noted where scarping was highest at southern ends of beaches which experienced higher amounts of erosion. Whilst evident that higher scarps took longer to recover across the study beaches, this requires further study to ascertain whether this trend occurs regardless of storm aspect, and whether this occurred consistently across NSW beaches. Further studies should be conducted to determine whether scarping from regular south-eastly waves from storms behave in a similar manner to the unusual storm aspect of the June 6th event. Studies should also consider the level of development on dune systems, and whether the presence of infrastructure such as dwellings impacts upon recovery time due to a lack of vegetation to trap mobilised sand.

6.2.1 Limitations

LiDAR datasets are an effective and powerful tool in assessing morphological changes of beach-dune systems. The LiDAR runs taken on the 15th of June and 29th of November were restricted in usefulness due to the lack of pre-storm LiDAR to compare to. By having consistent LiDAR runs, if pre-storm data was available, a more accurate insight into storm impact could have been ascertained through determining volume change, and allowing for profiles to show alongshore change and how scarping changed the face of the foredune. Whilst storms cannot be predicted in occurred or severity, having LiDAR within two years of an event could provide a basis for storm impact to be assessed with.

Comparing the post-storm LiDAR Tin and the recovery LiDAR Tin exhibitss good alongshore variation between the two points in time, however day-to-day and week-to-week variations which naturally occur as part of cyclical fluctuations (i.e. accretion and erosion) are omitted when comparing these profiles.

Moreover, the usefulness of the LiDAR is limited due to difficulties in penetrating dense vegetation, as evident in the three-dimensional visualisation of the DEMs providing high pyramidal shapes in the TINs indicating a likely source of error for comparison. This may potentially cause error for determining scarp height, however it is possible to remove vegetation through determining whether the unusually high areas correspond to vegetation in aerial imagery and adjusting DEMs.

LiDAR is also an expensive tool to acquire for coastal managers which can limit its usefulness.

6.3 GPS Surveys and Vegetation Assessment

RTK GPS surveys were undertaken by Tom Doyle and the author during the June to November period. The surveys undertaken immediately post-storm and at monthly intervals until September by Tom Doyle were conducted to examine beach-dune change during the recovery and to address the primary aim of investigating whether scarp height influences the length of recovery. The vegetation assessment also allowed for an examination of any trends surrounding whether species present along dune scarping have an influence on recovery through slumping. Vegetation assessment and GPS surveys were undertaken for at least two profiles at Warilla beach, Woonona beach, Werri beach and Perkins beach (See Appendix 1). A comparison of similar vegetation at profiles was conducted to examine if volume change and therefore recovery of the profile was influenced upon by different species of vegetation. The profiles Woonona north (Woon_N), Perkins (Perk_S2-more northern profile), Warilla (Warl_Mnorthern end) and Werri (Werri_N northern profile) exhibited the similar native vegetation present, predominantly *Spinifex sericeus* occupying the front of the foredune, with shrubs including *Acacia longifoliia* var *sophorae* and *Leptosperum laevigatum* present at the back of the foredune. The recovery volumes for each month are outlined below:

Werri N

Month	Volume m^3/m
12/06/2016	663.4889
27/07/2016	727.1583
08/09/2016	629.4959
17/10/2016	624.1399
21/11/2016	625.6024

Warl_M

Month of Recovery	Volume m^3/m
10/06/2016	638.6456
18/06/2016	679.284
24/06/2016	674.6253
27/07/2016	678.152
08/09/2016	670.5589
17/10/2016	666.869
21/11/2016	618.3662

Woon_N

Month	Volume m^3/m
10/06/2016	309.6925
18/06/2016	325.5044
24/06/2016	337.3599
27/07/2016	374.0304
08/09/2016	347.1164
17/10/2016	353.2863
21/11/2016	356.7715

Perkins

Month	Volume m^3/m
10/06/2016	406.578
18/06/2016	465.8554
24/06/2016	481.3177
27/07/2016	489.2757
08/09/2016	516.1899
17/10/2016	459.7542
21/11/2016	475.6075

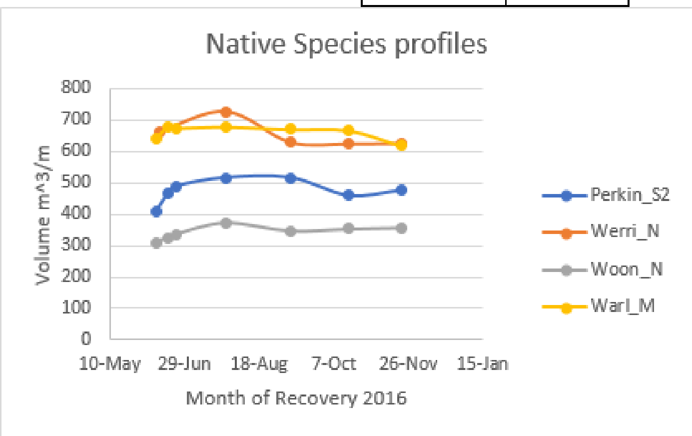


Figure 51 Profiles surveyed with dominant native pioneer vegetation.

Chrysanthemoides monilifera (Bitou Bush) is a weed of national significance and is considered to have detrimental impacts upon dune stability (see Werri beach in Literature review). This shrub was examined at monthly intervals at profiles with volume change outline below.

Perk_S3

Month	Volume m^3/m
10/06/2016	421.6369
18/06/2016	463.4192
24/06/2016	477.6822
27/07/2016	490.2276
08/09/2016	508.9128
17/10/2016	470.2467
21/11/2016	474.5828

WooMb

Month	Volume m^3/m
10-Jun	263.8066
18-Jun	280.1065
24-Jun	290.8238
27-Jul	306.9726
8-Sep	336.7319
21-Nov	335.3352

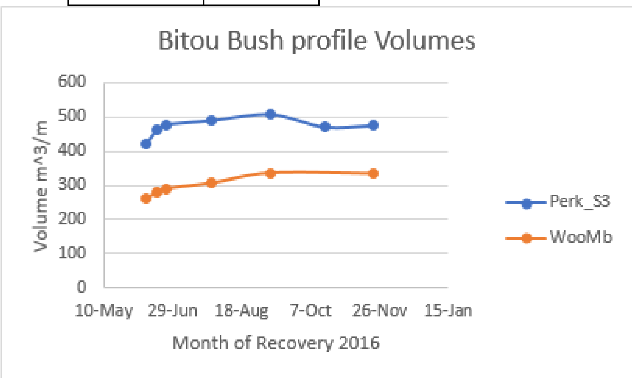


Figure 52 Profiles surveyed with the dominant shrub

Whilst the two profiles differed in dominating vegetation. It appears that pioneer species influenced beach-dune recovery through a faster rate of sand accumulation. Pioneer species allow for greater sand trapping in the root system compared to established shrubs (Figlus et al. 2014).

6.4 Relevance of study in coastal management

This study is of importance to the coastal management community because understanding major erosional impacts of storms such as scarping, can allow for more informed management of coasts, considering the threat of future sea level rise with climate change and increasing storm intensity. This study examined the relationship between vegetation and storm impact and recovery of beach-dune systems, namely whether scarp height influenced the rate of recovery of the foredune through slumping.

The study noted that higher scarping of beaches seemed to maintain a higher scarp with a more vertical cut for a longer period of time. The study also noted there is a possible trend between pioneer species inducing scarp recovery through slumping at a faster rate when compared with established shrubs. Further research into vegetation characteristics which allow for a faster accretion of sand is important for coastal protection of assets through utilising the dune system as a buffer zone.

Further investigation into scarping is crucial to determine if vegetation plays a larger role in the height of scarps produced from intense events, or whether aspect is a more crucial factor as seemed to be the case with this study due to the highest scarping occurring on all beaches at the southern ends of the beach regardless of vegetation present. The presence of shrubs did seem to create marginally higher scarps which maintained their shape for longer during the recovery process but this needs to be further investigated in a larger study.

6.5 Management implications

Coastal management is reliant upon accurate data to make informed decisions for the benefit of the entire coastal zone. This study attempted to determine the influence of vegetation on the foredune in influencing the initial level of erosion with the storm impact, and the rate of recovery during the following months.

GPS surveys conducted before and after storm events such as the June 6th event are a useful method in ascertaining how storm events influence beach-dune systems, particularly tracking morphological features such as scarping during the recovery process as well as volume change of the system. When considered with vegetation profiling and the use of LiDAR to create TIN DEMs to track morphological changes immediately post storm, these are useful methods to gain an understanding of storm impacts and processes of recovery. GPS surveys of profiles are an irregularly operated method of monitoring recovery but capture limited points in time. These surveys are highly significant and useful to coastal managers as processes observed can be used as a quantitative dataset to allow interpretation to calculate future system response to storms of differing magnitudes.

LiDAR data has been used to create TIN DEMs allowing for comparison through time to identify visually areas of scarp change. By identifying trends of consistent erosion, coastal managers can make better informed decisions when assess revegetation works due to differing species of vegetation influencing dune stability (Luna et al. 2011).

7. CONCULISON AND RECOMMNEDATIONS

Beaches along the south coast of New South Wales were heavily impacted by the June 6th storm event. This event saw high levels of erosion of the coastline resulting in erosional scarping of the foredune, undercutting of walkways, damage to coastal infrastructure such as dune fencing and removal of established vegetation. The recovery process saw slumping of dune scarps with pioneer vegetation revegetating the scarp and gaining sand at the toe of the scarping to allow for potential incipient dune formation. With the extensive coastal populations across Australia, coastal managers need to effectively manage beach-dune systems through utilising and implementing effective management programs. These programs should be based on substantial knowledge regarding beach-dune processes which operate on NSW beaches, in conjunction with documenting and understanding physical and morphological features of the beach-dune system.

This study had a primary aim of determining whether a trend exists between the height of dune scarping and the length of time taken for scarping to recover through slumping, in light of the highly erosive June 6th event. This involved visual analysis of immediate storm-impact photographs and recovery photographs, LiDAR analysis, GPS surveying and vegetation surveys examine scarp shape and height through time. The study focused on 4 beaches, with a total of 7 beaches examined.

The results identified that higher erosional scarps where all pioneer vegetation was stripped and shrubs dominated the scarp, tended to retain a vertical cut and higher height for a longer period of time during recovery when compared with smaller erosional scarps. Smaller scarps were seen to slump at a faster rate, with pioneer vegetation trapping sand more effectively than shrubs therefore allowing slumping to occur more quickly. This reflects the study undertaken by Figlus et.al (2014) which examined the influence of dune vegetation on wave erosion. This was examined using small scale modelling in a flume which demonstrated that the presence of vegetation significantly reduced erosion of dunes and reduced scarp retreat. The study noted the presence of mature plant roots (e.g. shrubs) reduced erosion of dune volume more effectively than less mature roots, such as pioneering grasses (Figlus et al. 2014).

This finding therefore may reflect why the vertical cut present at study locations with high scarps remained intact with less influence from slumping for longer, because established vegetation roots stabilise sand more effectively than pioneer vegetation (found on smaller scarps). This is of high importance showing the potential of coastal management to pursue further research into vegetation types and recovery rates as a form of stimulating post-storm recovery.

7.1 Recommendations

The management of beach-dune systems in response to storm events should address issues particularly relevant to short term planning period to create effective solutions to issues which threaten the coastal environment and pose safety risks, such as undercutting of walkways and dune fencing and high erosional scarps. Current storm impact management strategies employed are effective in ensuring public safety such as timely closure of walkways where undercutting has occurred and signage indicating unstable erosional scarps. This is an important management strategy that should continue to be used to immediately mitigate potentially dangerous storm cuts.

Based on the study indicating a trend exists between scarp height and length of recovery time, several recommendations are suggested for coastal managers.

First, where possible, consistent LiDAR acquisition would be beneficial in detailing initial storm impact. LiDAR enables detailed morphological assessment through the generation of TIN DEMs. Acquiring LiDAR at regular intervals would be highly beneficial in allowing for storm impacts to be assessed through derived profiles and three-dimensional viewing of scarping as undertaken in this study. Comparison of immediate post-storm LiDAR with pre-storm LiDAR would provide managers with updated LiDAR sets for comparison, allowing for cataloguing of the magnitude of storms and the subsequent impacts and recovery to help predict future storm impacts.

Secondly, consistent photographical evidence of storm impacts such as erosional scarps allows for visual assessment of recovery through time. This study showed that visual comparison of immediate post-storm photographs with recovery period photographs can depict natural slumping over a period of time. Again, this evidence can be compiled to document storm impacts of a certain magnitude. However it is recommended that photographical evidence is accompanied by communication and collaboration between all stakeholders regarding management in practice immediately post-storm events to ensure detailed records of management can account for changes depicted in photographs.

Thirdly, this study has demonstrated that erosional scarps as a result of intense events are an important storm impact to address to ensure public safety. This study recommends further investigation into the influence of vegetation on scarping. Whilst shrub dominated scarps tended to retain their shape and height for a longer period of time (e.g. Currarong beach), this trend needs to be examined at a larger study scale. If it is further reinforced through larger scale studies that higher scarps take longer to recover irrespective of storm direction and that the vegetation present does influence recovery, management plans regarding dune vegetation may allow for more targeted vegetation works to minimise erosional scarp impacts, and to induce recovery at a faster rate.

Finally, where possible, proactive policy making aimed at addressing known hazards at coastal hotspots such as Collaroy-Narrabeen as part of a holistic longer term coastal management can aid in reducing the need for emergency response with localised protection which may transverse impacts alongshore (Lord, 2016). Through increased dialogue surrounding long term issues such as long term recession and sea level rise, a combined short-term focus with increasing emphasis on long term management of coasts may provide more feasible management strategies than an overreliance on emergency management, which can be costly and only provide a temporary solution.

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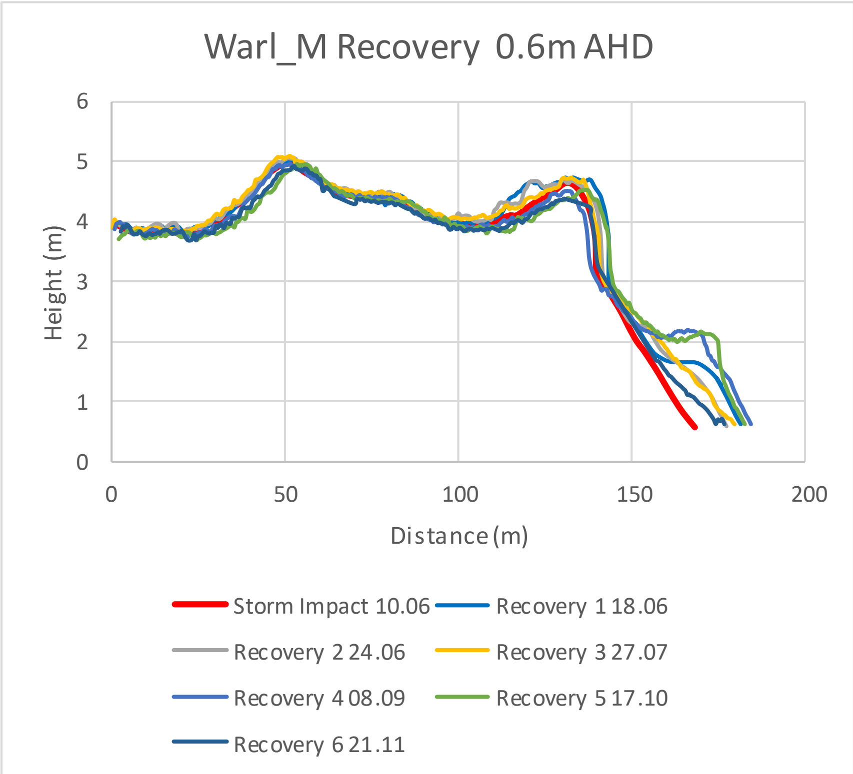
Appendix 1

RTK recovery profiles:

Warilla



Month of Recovery	Volume m^3/m
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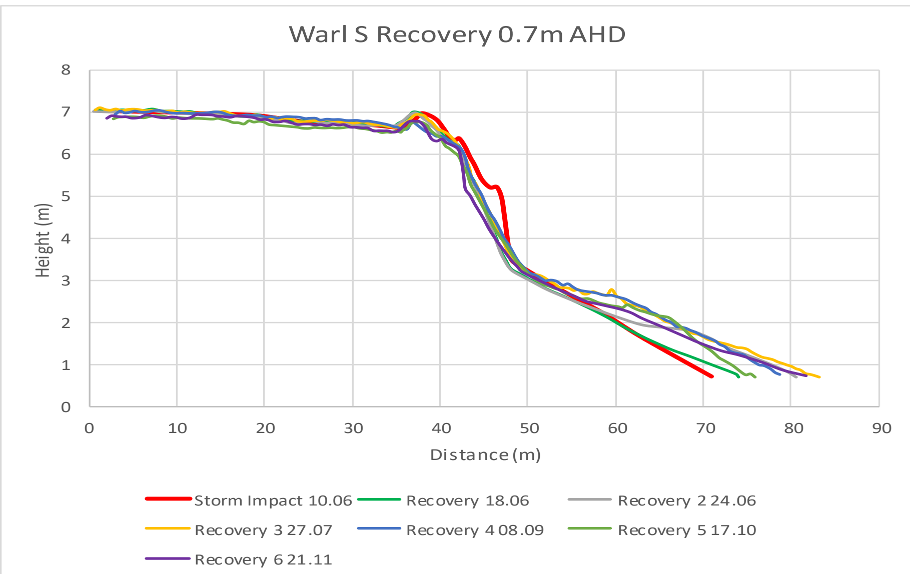
18/06/2016	679.284
24/06/2016	674.6253
27/07/2016	678.152
08/09/2016	670.5589
17/10/2016	666.869
21/11/2016	618.3662



Month of Recovery	Volume m^3/m
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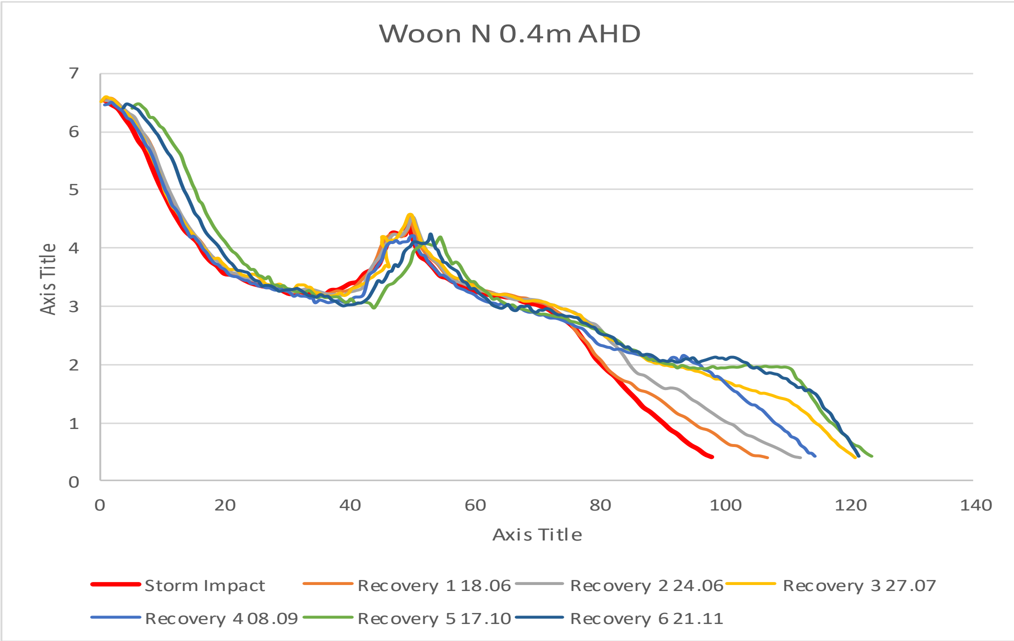
08/09/2016	360.6929
17/10/2016	348.135
21/11/2016	354.98



Month of Recovery	Volume m^3/m
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18/06/2016	355.3258
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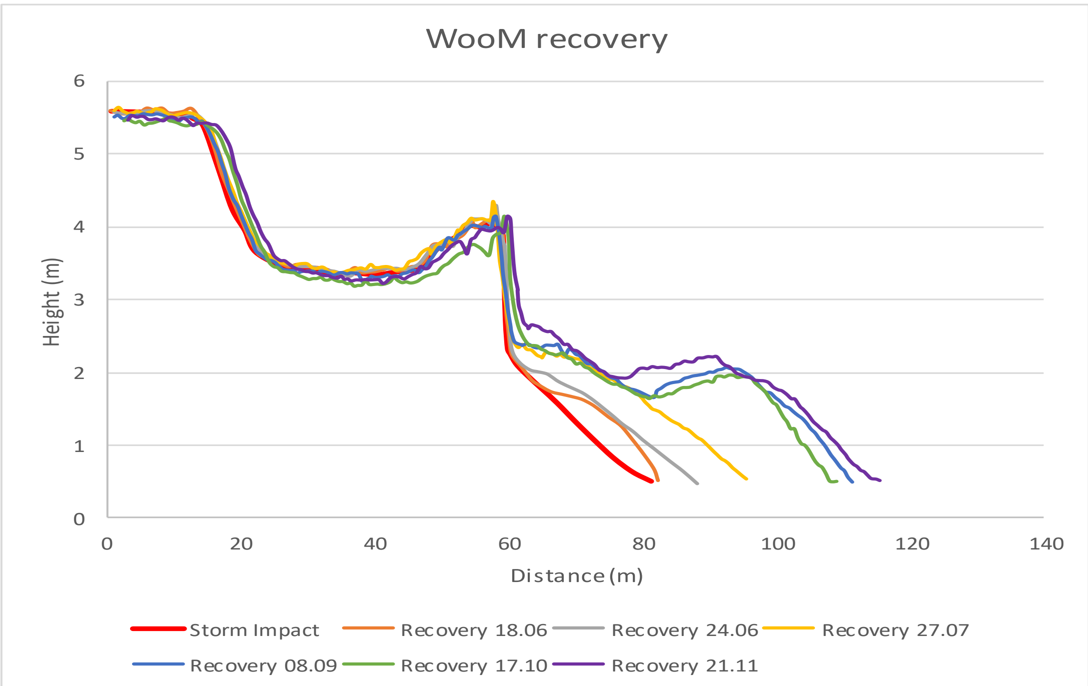
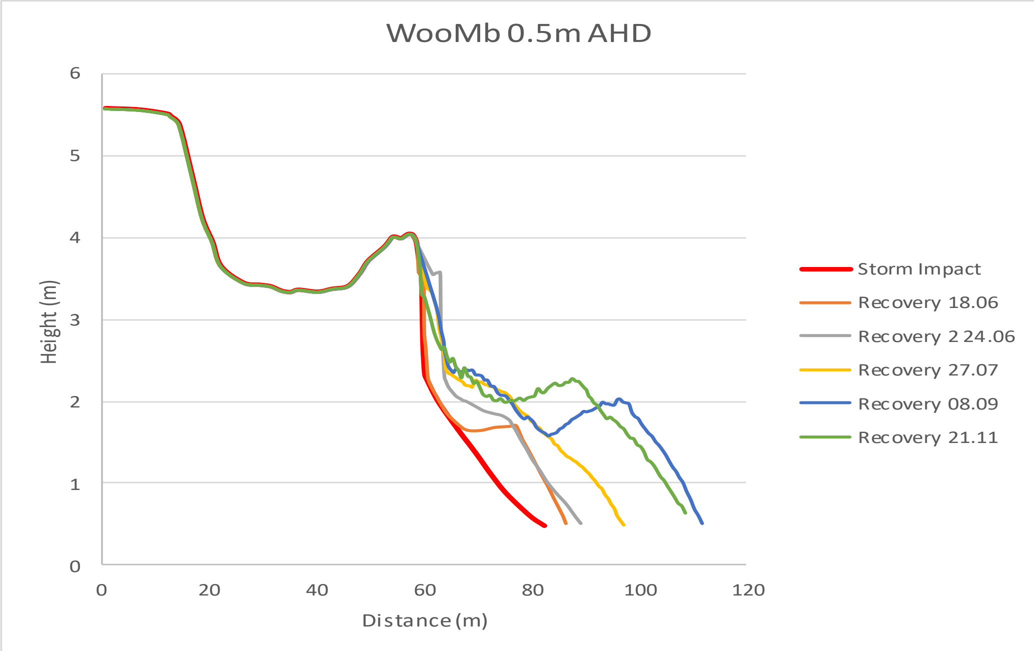
17/10/2016	348.135
21/11/2016	354.98

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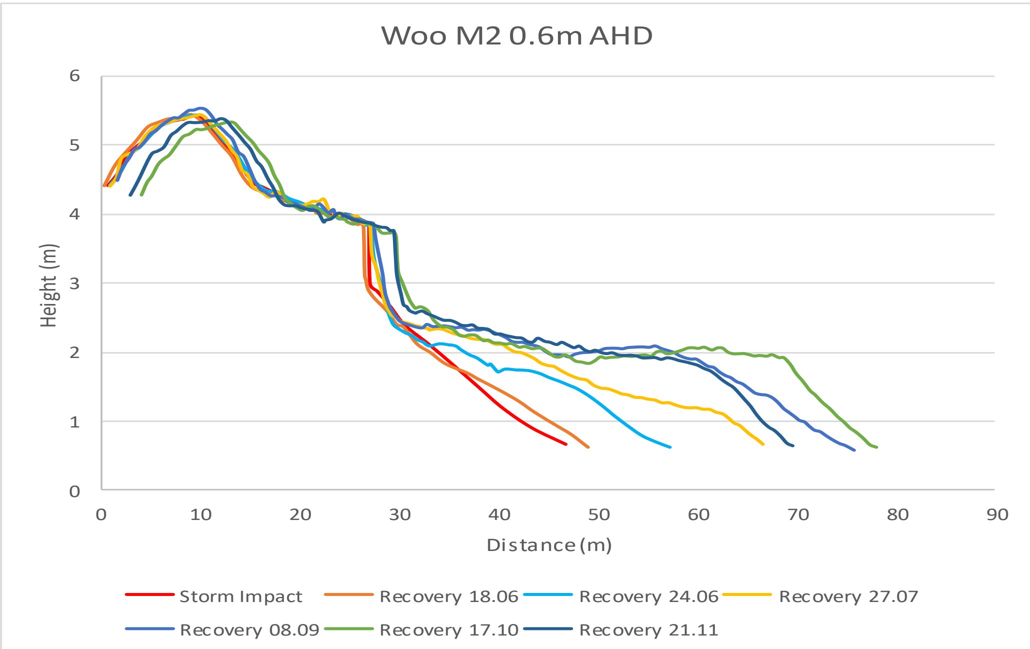
Recovery 21.11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Storm Impact
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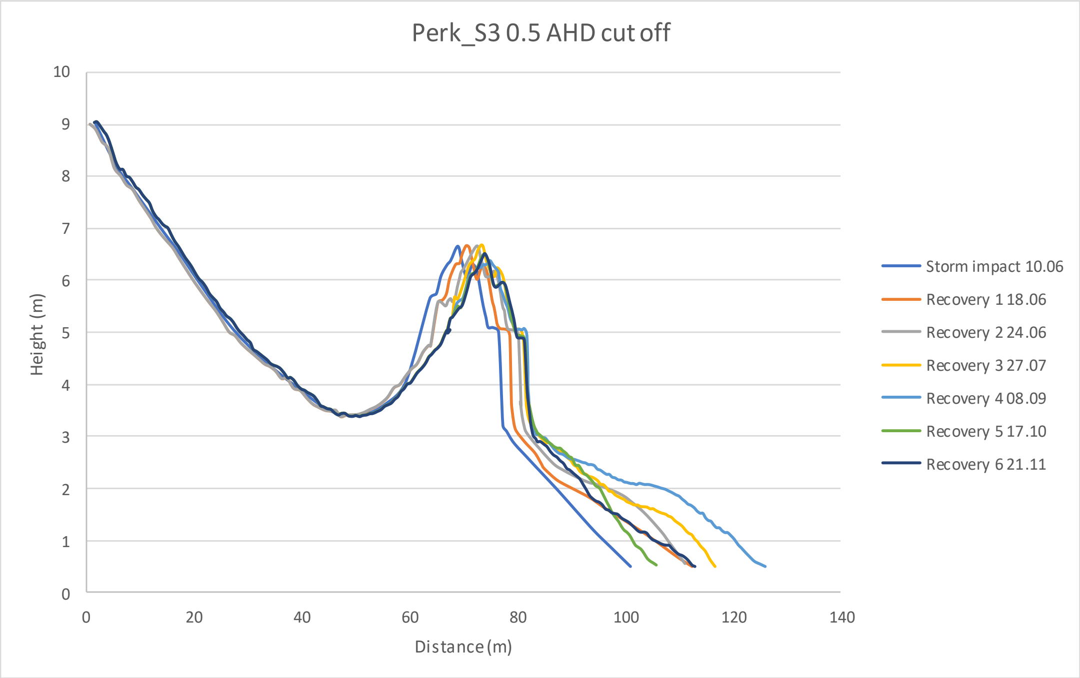
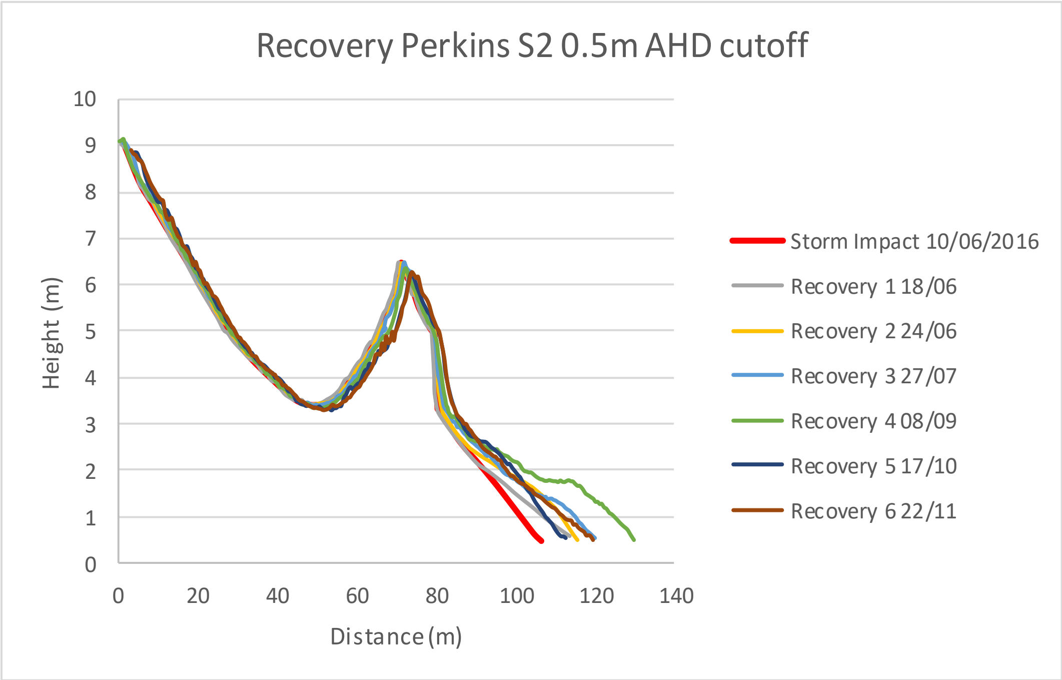
Recovery 21.11

Perkins Beach





Appendix 2

For excel profile calculations- see USB folder appendix two for GPS surveys and volume calculations.